

THE ELECTRONICS & COMPUTER MAGAZINE

SEPTEMBER 1997

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**FREE
SUPPLEMENT
VALVES IN AUDIO**

**FOCUS ON:
SURROUND SOUND**

**CHIPCARD
READER/
PROGRAMMER**

**CENTRONICS
RELAY CARD
CHARGING
BOOSTER**



September 1997 Volume 23
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**16-page SUPPLEMENT on
AUDIO projects
and allied information**
Centrefold

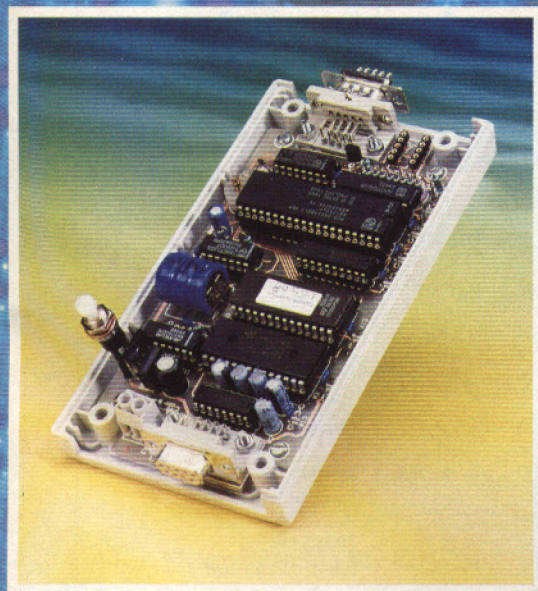
Chipcard reader/programmer



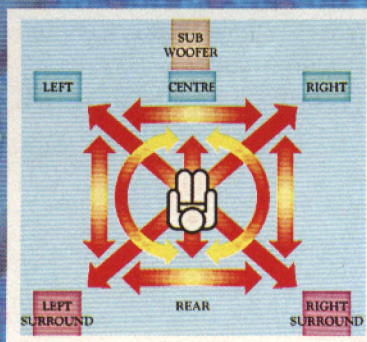
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electronics on-line valves on the Internet

Further to the information in this month's 'Extra' supplement which is entirely dedicated to valve technology for audio electronics, we rummaged around on the Internet to see what may be found on this subject. Well, a lot, as it turns out, so let's have a look at some interesting sites.

by our editorial staff

If you employ one of the search machines available on the Internet to look for instances of the word 'tube' or 'valve', you will not fail to notice that this subject is still very much alive. While surfing the net you will also discover that valves are not only popular with the high-end audiophile fraternity. In fact, valves are still widely used in PA (public address) systems, transmitters, etc. Consequently, the information provided by the net on valves goes in many directions. To stay in line with the subject of this month's supplement, we will limit ourselves to audio amplifier designed based on valves.

To start with, have a look at the site run by **Evacuated Envelopes - the on-line valve amp magazine** at <http://www.hillier.demon.co.uk/evac/>.

This site contains lots of information on valve databooks, suppliers of valves and valve-related magazines; there is even a 'tube' newsgroup for enthusiasts.

There are also a number of private

individuals who have produced their own Web page on the subject of valves. For example, **Kevin's Vacuum Tube Audio Web page** at

<http://www.ultranet.com/~kennedyk/index.html>

which is packed with data while also offering links to other sites.

Those of you with an interest in the designs by H.H. Scott are advised to have a look at the

Vintage H.H. Scott Resources

posted at <http://www.pyrotechnics.com/~jbyrns/index.html>.

Here you find a bit of history, adjustment tips for the amplifiers, and photographs. Circuit diagrams of these amplifiers may be found at, among others,

Tube Electronics

(<http://www.ccdemo.org/SportsAndHobbies/TubeElectronics.html>).

There are also valve audio fans who have taken the trouble of describing and showing their (home made) valve amplifiers on a web page. Two addresses are worth mentioning.

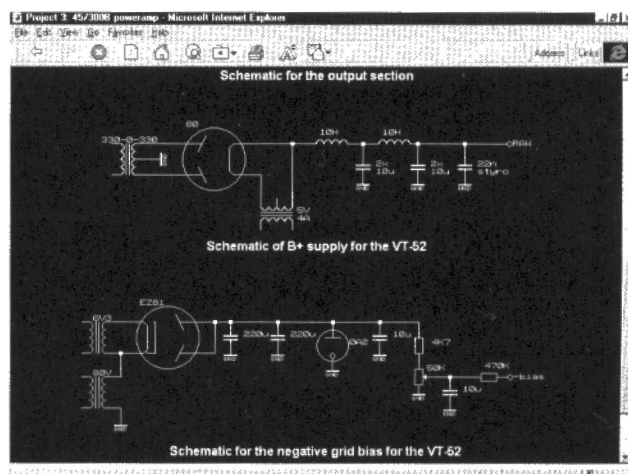
Vacuumtube Hi-Fi Audio

(<http://www.noord.bart.nl/~booster/>) describes, among others, a KT88 30-watt monoblock amplifier.

The Phaeton homepage

(<http://www.xs4all.nl/~jdekort/home.html>) shows a variety of designs, including a preamplifier, a power amplifier and a guitar amplifier.

Finally, if you want to know who is still in the business of selling valves, several suppliers are present on the Internet. The German company **Schuricht**, for example (<http://www.schuricht.de/>), supplies lots of valves besides other electronic components. (975057-1)



The logarithmic law of usefulness

How can a society survive twenty-five years of exponential technology growth?

During the past twenty-five years, we have witnessed a rate of progress in information technology that seems beyond comprehension. An increase in the characteristic parameters by a factor of between one thousand and one million has been the rule rather than the exception. Progress in, for instance, the field of transportation took centuries before a factor of one thousand was accomplished: a horse cart, an early automobile and a supersonic aeroplane cover the distance of thirty kilometres in one day, one hour, and one minute, respectively. A factor of one thousand in only ten to fifteen years thus means a real revolution. But why can we apparently cope so easily with this exponential growth. How can we so easily absorb and implement such progress without being confused by its implications? My answer is that the perceived progress, the increase in usefulness, is not exponential, but linear. In other words, usefulness is a logarithmic function of technology.

In the electronics industry, Moore's law describing the developments in microelectronics is a well-known and widely accepted hypothesis. Gordon Moore, founder of Intel, formulated it in 1964 as follows: "The amount of information storable on a given amount of silicon doubles about every year."

Since 1970, the doubling period has increased to about 18 months. Moore's law can be formulated alternatively as: *the size of the details that are carved in the semiconductor material decreases*

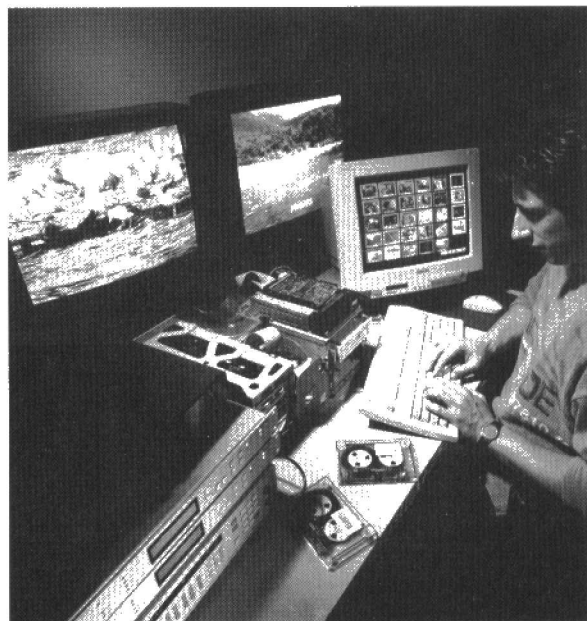
By Dr T.A.C.M. Claasen
Director of Research at Philips
Research Laboratories, Eindhoven

by a factor of two every 18 months.

It is interesting to see that this also causes the transmission speed of signals between elements to increase and the heat dissipation to decrease. All well-known stuff and, even though it is expected to be limited by hard physical or economic boundaries, it still holds as – as I will show – will hold for a number of years to come.

What is equally interesting is that Moore's law holds not only for progress in microelectronics *per se*, but also for progress in related areas such as storage and software. There even exists a twin law to Moore's law, called Parkinson's law, that reads:

memory usage of evolving systems tends to double every 18 months.



GENERALIZED MOORE'S LAW

A generalized form of Moore's law reads:

all performance indicators applicable to the field of information technology improve by a factor of two in a period of one-and-a-half year to three years.

I will illustrate this with examples for three fields in information technology: microelectronics, storage and software.

Firstly, in *microelectronic* microprocessors, dynamic and static random-access memories (DRAMs and SRAMs), digital signal processors (DSPs) and application-specific integrated circuits (ASICs) have evolved during the past decade in such a way that the performance indicators (such as the number of transistors per chip and the memory size) have increased and geometrical feature size and the gate delay (related to the operational speed of the chips) have decreased. This resulted in exponential changes in the computing power, the memory capacity, and the speed of the chips, that is, the functional or secondary parameters, as I will call them. The fac-

tors indicating this exponential growth are different for the different qualities, but all are positive, relatively large and result in substantial growth.

Then we have the *storage systems*. The digital storage media – magnetic and optical discs and tapes – and the systems to read and write the data on these media have shown enormous progress. The performance indicators (such as the number of bits per carrier, the price per megabit, and the number of bits that can be stored or retrieved per second) for hard-disc drives (HDDs), digital tapes, and Compact Discs and their derivatives (CD-ROM and CD-i) have obeyed the generalized form of Moore's law without failure. This has resulted in the improvement of the secondary parameters which I formulate, once again, as the memory size, the speed of data storage, and the price per bit. The first two increase, the last one decreases.

In the field of *software* we can think of a telephone – now completely built in software – the user interface of a television set, the set-top boxes needed for digital television, and the databases together with the browsers that make them accessible. The growth these systems have gone through is enormous. The program size, the number of lines of code that are necessary to realize their functions, and the amount of data needed for this in huge databases show exponential growth.

Developments in these fields have not occurred independently of each other.

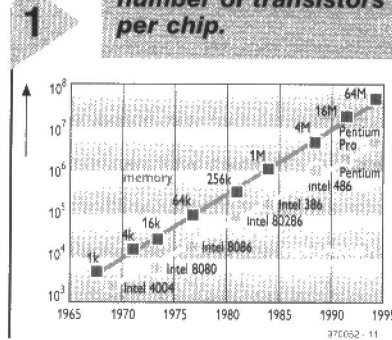
The increase in the number of transistors on a chip design could not be managed without the use of computer-aided design software. And software could not have had such an impact if there hadn't been hardware systems with chips on which it could be run. And this again would not have been possible if there hadn't been huge and fast storage systems available. Whichever way you look at it, it is indisputable that enormous progress has been made in these fields over, say, the past twenty-five years. But will it go on for the next twenty-five years?

HARD LIMITS

Even when Moore first formulated his law, one was more than aware of the limits to the growth described by his law. You could not shrink dimensions endlessly without meeting physical limits. However, limits are found not only in physics, but also in other areas. There are physical, economic, and what I will call 'design' limits.

The next ten to fifteen years we will have enough room to move on in the direction we are now going.

Chip complexity in number of transistors per chip.

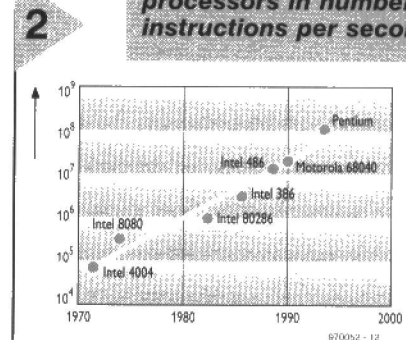


The examples I gave are randomly chosen and many more can be thought of without effort. I will start with the hard physical limits. If you look at, for example, the size of a bit in a magnetic medium, it is evident that you cannot reduce it below the size of the magnetic domains themselves. The very properties that allow you to store a bit in a small area on the medium disappear if you shrink the dimensions too much. Now we need an area of about $1 \mu\text{m}^2$ to store one bit. Such an area contains a number of grains that have the magnetic properties necessary to be able to read and write a bit. The size of a magnetic grain is $0.0007 \mu\text{m}^2$ and since we need – because of signal/noise requirements – about one hundred grains in one bit, there is still room for improvement here. Extrapolating today's course of events, we can diminish the size per magnetic bit to $0.07 \mu\text{m}^2$. This leaves room for another ten to twelve years of improvement in this field. Beyond this, thermally stable patterns with one magnetic particle per bit can, in principle, be made. A lot of research work into the reading and writing mechanisms will have to be done before this can be applied in a working device, though.

In solid-state memories, a similar argumentation leads to the conclusion that from the one million electrons per cell that we have now down to the minimum number of one hundred, there is still room for improvement.

However, IC process technology may be the limiting factor for progress. The smallest details that can be made are determined by the smallest fea-

Computing power of micro-processors in number of instructions per second.



tures that can be resolved in lithography, by the optical properties of wafer steppers, and the wavelength of the light that is used. By using a wavelength in the deep ultraviolet region, together with improvements of the optical system in wafer steppers, it is possible for the semiconductor industry to advance in the chosen direction for the next ten to twenty years.

In optical recording, the bit size may also be limited by the wavelength of the light that is used to write and read the bits. But, in principle, we can reduce the wavelength of the lasers used in optical recording, provided that we can produce working lasers with smaller wavelengths. We need not be limited to visible light here.

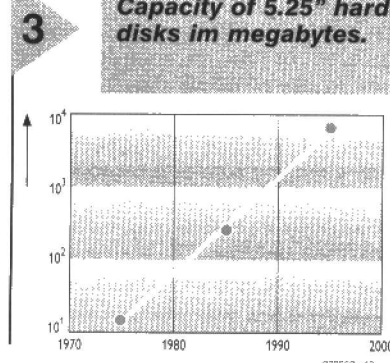
REAL LIMITS?

I now come to economic factors. When Moore formulated his law, it was estimated that by the year 2000, the cost of starting a new IC factory would be one billion dollars. At that time, this was a large and unacceptable amount of money, especially when compared with the four million dollars such a factory cost then. However, today about twenty new IC factories are being built worldwide with each of them costing around one billion dollars. Profits in this sector have risen so high, apparently, that this amount of money is longer a real limit. At least, for the time being it is not.

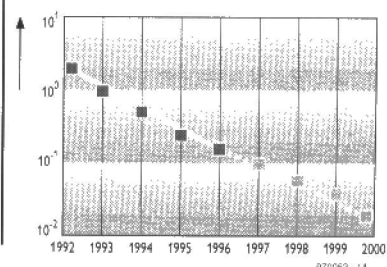
Are there no real limits then? Will they all shift further away as we near them?

I am not so sure about that. There is one field that presents us with unsur-

Capacity of 5.25" hard disks in megabytes.



Cost of storage on hard-disk drives in dollars per megabyte.



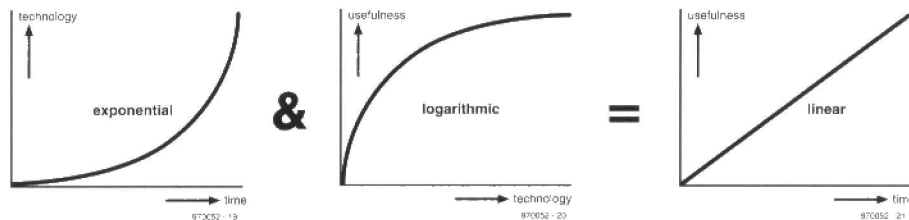
Progress in information technology

Field of information technology	parameter	time dependence	coefficient value
Microelectronics	- computing power - solid-state memory - speed	$\exp(c_1 t)$ $\exp(m_1 t)$ $\exp(s_1 t)$	$C_1 \approx 0.33/\text{year}$ $m_1 \approx 0.28/\text{year}$ $s_1 \approx 0.75/\text{year}$
Storage	- memory - speed - price/Mbyte	$\exp(m_1 t)$ $\exp(s_1 t)$ $\exp(-pt)$	$m_2 \approx 0.32/\text{year}$ $s_2 \approx 0.75/\text{year}$ $p \approx 0.70/\text{year}$
Software	- software size	$\exp(c_2 t)$	$C_2 \approx 0.31/\text{year}$

Technology is a function of a number of parameters that all vary exponentially with time. Coefficients are large, and roughly vary between 0.25 and 0.75. This implies that technology has advanced in the last 75 years by a factor between 518 and 139×10^6 . A large increase indeed. The usefulness has not increased with such a large factor, and this brings me to the logarithmic law of usefulness:

$$\text{usefulness} = \log(\text{technology})$$

with $\text{technology} = f(\text{computing power, speed, memory, ...})$ and given the exponential increase of the parameters this results in a linear increase of usefulness with time



mountable problems and that is the third factor I mentioned: the one I characterized with 'design'. Let me first give you an idea what I mean by taking an example from my own experience. When we in Philips Research started the IC Design Centre, back in 1985, I spoke to the plant manager of an IC factory in Southampton. In his development department, the average design efficiency of his projects was 5000 transistors per man per year. It is not so hard to understand that, now that chips with a million transistors are possible, these cannot be designed by one person since it would take 200 years. It would even take 100 cooperating people two years, which is too long and not manageable. From experience, we know that we can do it

faster. Nowadays, chips containing a million transistors are designed by teams of a few people in half a year (see box on Melzonic).

Indeed, an exponential increase again. But we could not have done this without the help of automated design tools and methods. And I am confident that we will manage chips with 10 million or even 50 million transistors in the same period and with the same number of people in the coming years. It will be hard work, but I have a feeling that we will succeed.

However, I am not so confident about design progress in another field: that of software. In fact, we are even passing an abyss as it were. In software design, a complete transformation of the prevailing culture has to take place if we are to be able to cope.

I know of more failures of software projects – failures in particular with respect to timing – than IC design projects dealing with the same amount of complexity. Why is that, I wonder. One aspect, an important one in my opinion, is that in software design one is hindered by the inherently useful opportunity of being able to change things up to the last minute. Again, compared with IC design, where every change means a new processing cycle of about three months, this looks like an advantage, but may well be a disadvantage after all. In consumer products, for instance, there is not much re-usable software in existence and where it does exist it is not re-used. Given the complexity and the

extent to which software is playing a role in today's progress in technology, software designers should and can learn a lot from IC designers. Formal methods and techniques will have to play a larger role than they do today. And I think they will.

None of the foreseen limits will really prevent us from advancing further in the direction that we have been going the past twenty-five years.

Moore's law, and the generalized form of it, will hold for at least another ten to fifteen years.

NEW LAW

I will now come back to my original question. If growth is exponential in so many areas, it is surprising that it can be absorbed by society. Imagine a philosopher coming from a far-away galaxy, not yet exposed to microelectronics. What would she have predicted given the sustained sharp exponential growth of technology over the past twenty-five years? *Chaos, social disorder*, or in any case an *unrecognizable society* is my guess. But we all know that we have coped.

We have been able to absorb this technology and use it to increase our comfort. Why is that?

Let me take you back twenty-five years. We had a home, a car, a television with six channels, a telephone, a tuner, a gramophone, and a newspa-

Travelling salesman

The travelling salesman problem is a well-known example of the class of combinatorial optimization problems. Given a number of towns and the distances between them, what is the shortest route a sales representative can take to visit each town once? A visit to six towns presents 60 possible routes, but one to 12 towns presents almost 20 million possible routes. A visit to n towns presents $n!/2n$ possible routes. With the exponentially increasing capacity of the computers used to solve this problem for a large number of towns, the optimal solution is approached in ever smaller steps. Problems of this sort also exist in IC design, where economizing on the length of the interconnects is the goal.

per, and lived comfortably with all that. We did not have things that we have now, such as a television set with up to a hundred channels and a remote control, a GSM, a fax, an answering machine, a PC with CD-ROM, a CD player, a CD-i, a VCR, and the Internet. Apparently, new products have readily absorbed and exploited the possibilities that technology offered. The exponential growth in technology has made this possible, but although the change is significant when you look at it from the user's point of view, this change is not so extreme. More so, when you consider the changes brought about in society. Nowhere is the exponential growth explicitly visible.

I would now like to postulate a new law: the *logarithmic law of usefulness*. By usefulness, I mean something like the impact of technology on our daily lives. The law I state holds that

usefulness is a logarithmic function of technology.

In turn, technology is only a linear function of computing power, operating speed, memory capacity, and perhaps a few other parameters. These parameters increase exponentially, as I have shown. So, technology increases exponentially. In combination with the law I stated, this means that usefulness increases linearly to an extent that we can grasp. I have not derived this new law analytically, but neither did Moore his law. I will, however, give you some examples and some observations from which you can get a feeling that the law is valid.

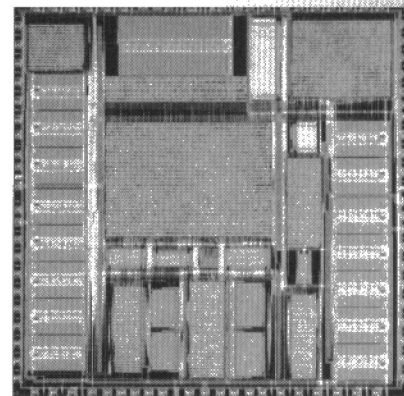
- A telephone handset containing ten preset numbers is helpful enough for most calls; a base station with some hundreds represents the next step in usefulness; a telephone book with 100,000 numbers will help you further, while for all possible telephone calls a world base with hundreds of millions of subscriber numbers is needed. The technology needed to provide these numbers increases exponentially while the usefulness increases only stepwise.
- If you compare the early personal computers with an 8086 processor and the operating system MS-DOS of ten years ago with today's Pentium and Windows 95, you must admit that the exponential growth in the arithmetic and memory capacity, and the number of code lines of the application have indeed made computers more useful. But not so much more as an exponential function would suggest.
- In speech recognition, a database of ten words and a system trained for

one speaker make hands-free dialling possible: simply speaking the number is sufficient to make the connection. Or, the ten preset numbers in your handset can be accessed with Peter, Mary, and so on. A thousand-word vocabulary that can be recognized as coming from more than one speaker could make your electronic products in the home react to commands from all members of the family. But a true dialogue or a dictation system requires recognition of all possible speakers, of all possible words, and thus requires an order of magnitude more operating and storage capacity. But in usefulness it is, in my view, just one step further.

- In data retrieval, you find the same hierarchy for a simple dictionary, an encyclopedia and the Internet.
- In data communication, the steps from telex to fax to e-mail required a huge increase in technological power to make incremental steps in usefulness possible.
- The software in television sets went from 0 byte and 20 push buttons to 30 kbyte for simple sets to 1 Mbyte for high-end television sets, with only a modest increase in the actual user benefit.
- Video cassettes of 180 minutes allow you to store one movie plus a bit of a second one. Tapes with twice as much storage capacity are not twice as useful, as it is more convenient to keep one movie on a separate tape.
- You may find it useful to have a thousand books, but if you are looking for something special you will soon revert to your local library of 100,000 books and if you don't find the answer there you may revert to the British Library or Library of Congress containing all books ever printed.
- A particularly interesting example of exponential growth is the evolution in communication technology. When depicted on a logarithmic scale, the traffic intensity shows an exponential increase over time. And considering the increase in comfort or the possibilities for use that this technology has brought us, it is indeed the one with the greatest impact on our lives.

Apart from these examples, I have a few other observations that support my law.

Firstly, seeing and hearing, as examples of human perception, are also logarithmic function of the provided inputs. Usefulness is also a perceived quality. And even when the sensors cannot be located and tested for their transfer functions, why should this



Some quantitative data:

die size	97 mm ²
technology	0.8 µm
number of transistors	1 million
design time	5 man-years
embedded memory size	160 kbit
embedded memory bandwidth	30 Gbit/s
worst-case power dissipation	2 watt
processing power	9 giga-operations per second

quality not also depend logarithmically on the inputs?

Secondly, a large number of the solutions that information technology provides fall into the class of combinatorial organization problems (see box on travelling salesman). Characteristically, the number of solutions to be investigated, that is, the complexity, grows exponentially with the number of variables, while the answer only brings you one step further.

Thirdly, we are all familiar with the human nature of collecting things until we run out of space for storing them. Only seldom do we stop collecting things because it is no longer useful. The advances in technology provide us with exponentially growing cellars and attics and we load them with information, only occasionally taking out something that we perceive as useful at that moment.

So far, my exposé about this new law. But what can we conclude from it? What do we learn? How will it influence our decisions? In my opinion, there are a few things we can learn from it. The first is that society can accommodate exponential growth of technology without pain.

We do not have to be afraid that technology will take over, because we can handle it.

The second is that if a society wants substantial improvements, for instance, to solve such things as traffic jams or improve the educational system technologically, fortunes have to be spent on research and development (R&D) to get there.

And, finally, we in industrial electronics research can still continue our work, while society eagerly adopts all our results.

[970052]



data acquisition system

hardware and software for an intelligent datalogger

The datalogger described in this article captures any measurement value which can be represented as a voltage. Nowadays, sensors or transducers are available for practically any physical quantity. Because these sensors convert their measured levels into a proportional voltage, the datalogger is suitable for many different applications, and easily adapted to a specific task.



Main Specifications

- ✓ autonomous storage of measured values
- ✓ up to 8 measurement points
- ✓ adjustable interval and number of measurements
- ✓ 8-bit resolution
- ✓ 32-kByte non-volatile data memory
- ✓ file format suitable for processing by spreadsheet or database program

Design by H. Weidner

The function of a datalogger is to capture and store a specified number of sensor measurement values at predefined intervals, and transfer the data, including date and time, to a PC in the form of a file. In this article we will look at an intelligent datalogger which relies on microprocessor control, and reduces the function of the PC to that of a terminal for setting the operating parameters, and for securing the data in DOS text format (for further processing) at the end of a measurement session. For the rest, the datalogger

board works on its own, and may be disconnected from the PC. This feature is particularly interesting if measurements are made which take several days or even longer.

The datalogger also has strong points when it comes to use 'on the road'. Once the operating parameters (configuration data) have been set, these are retained in memory, just as the measured data (but not the current time), even when the supply voltage fails.

The unit is powered by a small

mains adaptor, or, in the case of an emergency, by a 9-volt battery. This will last for a few hours given the datalogger's current consumption of 75 mA.

At the end of a measurement cycle the system waits for a command from the PC, which tells it to release its measurement data. The data, in turn, may be saved as a file (under DOS) for further processing by a suitable program like Lotus. The datalogger and the PC use the serial RS232 link for their communication.

MICROCONTROLLER WITH WATCHDOG

The circuit diagram in Figure 1 shows that the datalogger is a classic micro-

controller system built around an 80C31 (or an 80C51). The microcontroller has access to an EPROM (IC6) which acts as a program memory, and a RAM (IC7) for data storage. Port 0 of the microcontroller supplies the data-bits and the lower eight address bits. The two bit sets are separated by sending the ALE (address latch enable) signal to a 74HCT573 latch (IC5). Port 2 is

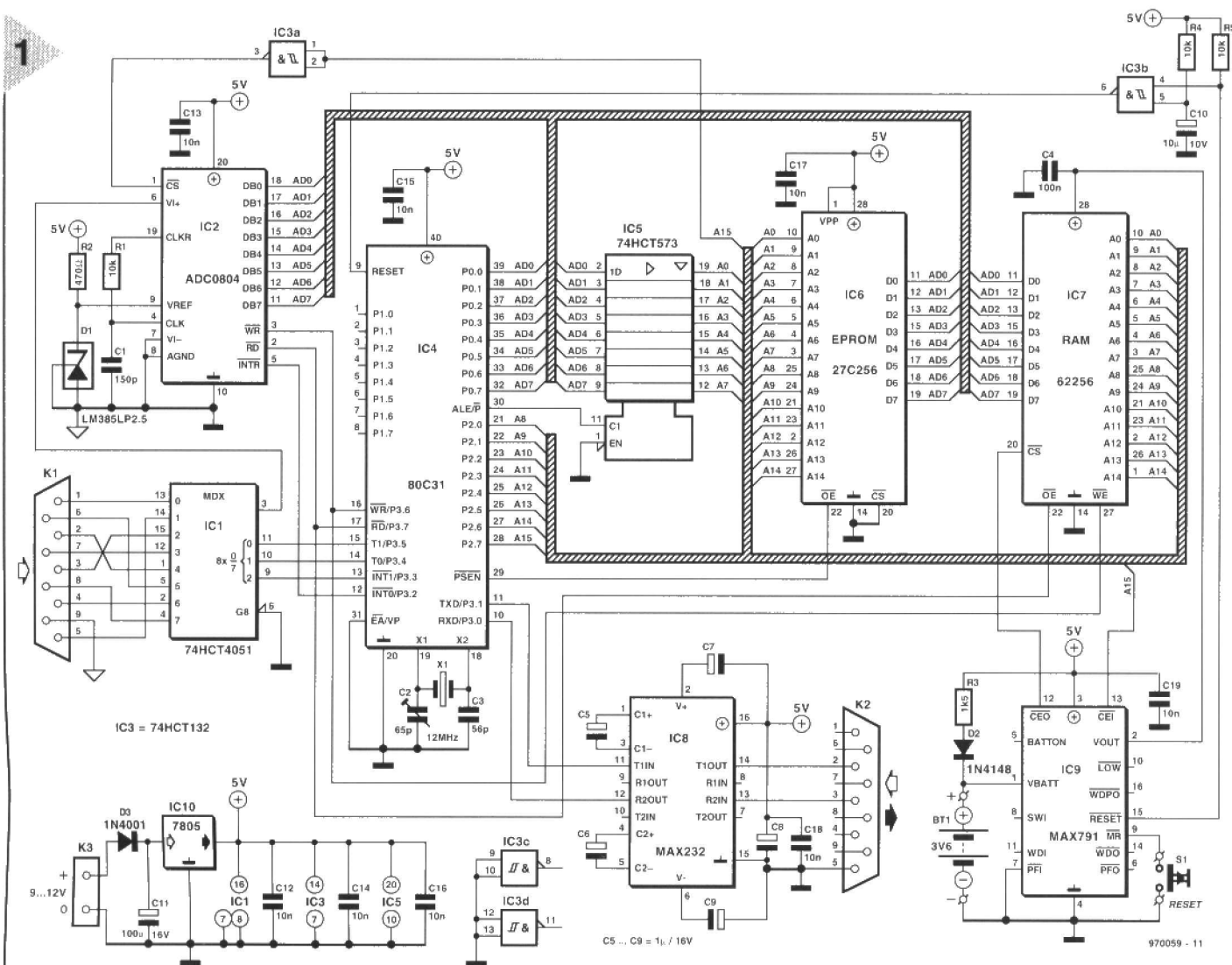
responsible for the upper eight address bits. The RAM used here is a type 62256 offering a capacity of 32,768 words of 8 bits. At eight measurement channels, that allows a maximum of 2048 measurement samples per channel. This number increases proportionally if the number of channels is decreased.

Port 3 has various functions. Port lines P3.0 and P3.1 are used for the communication with the PC. IC8, a MAX232 arranges the conversion of TTL signal levels used by the micro-

controller, using a write command (WR) to port line P3.6.

After a successful conversion, the INTR output of the A-D converter goes logic low, telling the controller to copy the data and store it in RAM. Incidentally, the maximum input voltage range of the A-D converter is defined as 0 to +5 V by the ground potential at VI- in combination with a 2.5-V reference diode, D1.

To be able to retrieve the RAM contents (measurement and configuration data) even if the supply voltage has disappeared, a *microprocessor supervisory circuit* type MAX791 has been added (IC9). This IC does a lot more than just acting as a simple watchdog,



controller system built around an 80C31 (or an 80C51). The microcontroller has access to an EPROM (IC6) which acts as a program memory, and a RAM (IC7) for data storage. Port 0 of the microcontroller supplies the data-bits and the lower eight address bits. The two bit sets are separated by sending the ALE (address latch enable) signal to a 74HCT573 latch (IC5). Port 2 is

analogue multiplexer. The analogue signal at the selected input (Ch1-Ch8) arrives at the signal input of the A-D converter via the X-output of the 4051. The ADC used here is the inexpensive and easily controlled ADC0804.

An analogue-to-digital conversion cycle is triggered by a short negative pulse at the WR input of the ADC. This pulse is supplied by the micro-

Figure 1. This circuit diagram of the datalogger shows a complete microcontroller system with an on-board RS232 interface for connection to a PC. A multiplexed A-D converter is used at the input side.

STATUS	Interface: COM2 Date: 01.07.1997 Time: 21:19:38
START	Test points: 1
STOP	Measurements p. point: 1
TRANSFER	resp. time of measurement: days 0 Time 00:00:00
STORE	Time until first measurement: days 0 Time 00:00:00
CLEAR	Time between two measurements: days 0 Time 00:00:00
END	Time until next measurement: days 0 Time 00:00:00
	Start of measurement: Measures taken: 0
	No. of power fails: 0
	Status: Datalogger idle
	Display test point: no / all Nr.: 1 F:0.50 Value: 0.0
	File name:
	Comment:

Data from datalogger expected!

Figure 2. Main menu of the control program which runs on the PC. The program is designed to run under DOS only. Although the program may cause erroneous results when run in a DOS window under Windows 95, the operation of the datalogger hardware is not affected.

even if that is its main function. The IC monitors the 5-volt supply voltage and feeds it to the supply pin of the RAM. If the supply voltage at Vcc drops below 4.65 V, a 3.6-volt NiCd (nickel-cadmium) battery takes over the RAM supply. At the same time, the RESET output (pin 15) drops low, resetting the microcontroller and enabling it to start up from a defined state. The same action is brought about by a small power-up network, R4-C10, or by pressing the reset key connected to the MR input of the MAX791.

CONTROL SOFTWARE

The software written for the data acquisition system is divided between the microcontroller on the one hand, and the PC on the other. No knowledge is required on the EPROM-based program executed by the microcontroller, as it remains 'invisible' to you, the user. The PC software, on the other

hand, does have a user interface. It consists of the program proper, called DES08PC.EXE, and a configuration file, DES.INI. Although the program can be run directly from floppy disk, it is recommended to copy all files into a suitably named

subdirectory on the hard disk.

After the program is launched, the display first shows author information and then the menu as shown in **Figure 2**. At the right side (fourth line from below) you can see the report *status: no datalogger connected*. This changes to *datalogger idle* when the datalogger hardware is switched on. At the left-hand edge of the screen you find seven menu options which may be selected with the aid of the arrow keys. The selection is confirmed by pressing the 'Enter' key. To be able to enter or change something in the right-hand field on the screen, you select the relevant parameter with the arrow keys, and then confirm the highlighted field by pressing 'Enter'. Next, you enter the new parameter and again confirm it with Enter.

Apart from the operating parameters (system configuration), the right-hand side of the screen also shows the status of the measurement processor:

Interface By pressing the Enter key, you switch between COM1 and COM2.

Time/Date: This indicates the system date and time, which also appears in the measurement protocol. The time/date can only be changed in DOS or Windows.

Test points: The number of measurement points (between 1 and 8).

Measurement p. point: The number of measurements (equals period/interval + 1).

Resp. time of measurement: Duration of the measurement (equals

COMPONENTS LIST

Resistors:

R1, R4, R5 = 10kΩ
R2 = 470Ω
R3 = 1kΩ

Capacitors:

C1 = 150pF ceramic
C2 = 65pF trimmer
C3 = 56pF ceramic
C4 = 100nF Sibatit
C5-C9 = 1μF 16V radial
C10 = 10μF 10V radial
C11 = 100μF 16V radial
C12-C19 = 10nF Sibatit

Semiconductors:

D1 = LM385LP2.5
D2 = 1N4148
D3 = 1N4001
IC1 = 74HCT4051
IC2 = ADC0804LCN
IC3 = 74HCT132
IC4 = 80C31 (DIL40)
IC5 = 74HCT573
IC6 = 27C256 EPROM (order code 956510-1)
IC7 = 62256 (100ns)
IC8 = MAX232
IC9 = MAX791
IC10 = 7805

Miscellaneous:

X1 = 12 MHz quartz crystal
K1 = 9-pin sub-D plug, PCB mount
K2 = 9-pin sub-D socket, PCB mount
K3 = 2-way PCB terminal block, raster 5mm
S1 = push-button, 1 make contact
BT1 = NiCd battery, 3.6V 60mAh, PCB mount
Plastic enclosure, approx. size 150x80x45mm
PCB, EPROM and disk, set, order code 970059-C
Disk only: order code 956010-1.

period/number)

Time until first measurement: Idle time before the first measurement; has no effect on period.

Time between two measurements: The interval between two measurements (min. 1 s).

If you only enter the number of measurement points and measurements, the program defaults to an interval of a couple of milliseconds. This may be very useful for test purposes.

The next field on the screen contains only status information which does not have to be changed. In addition to the two reports already mentioned, two other texts may appear after 'status': *measurement in progress* and *measurement finished*.

The line below *status*: offers the following program options:

Display test points By entering a measurement point number (channel), or all of them, you call up a diagram containing the current val-

Figure 3. Format of measurement data file (example).

01.07.1997	13:23:40	2.2	0.0
01.07.1997	13:23:50	2.2	0.0
01.07.1997	13:24:00	2.2	0.0
01.07.1997	13:24:10	2.2	5.0
01.07.1997	13:24:20	1.9	5.0
01.07.1997	13:24:30	1.4	5.0
01.07.1997	13:24:40	1.0	5.0
01.07.1997	13:24:50	0.5	5.0
01.07.1997	13:25:00	0.0	5.0
01.07.1997	13:25:10	0.0	5.0

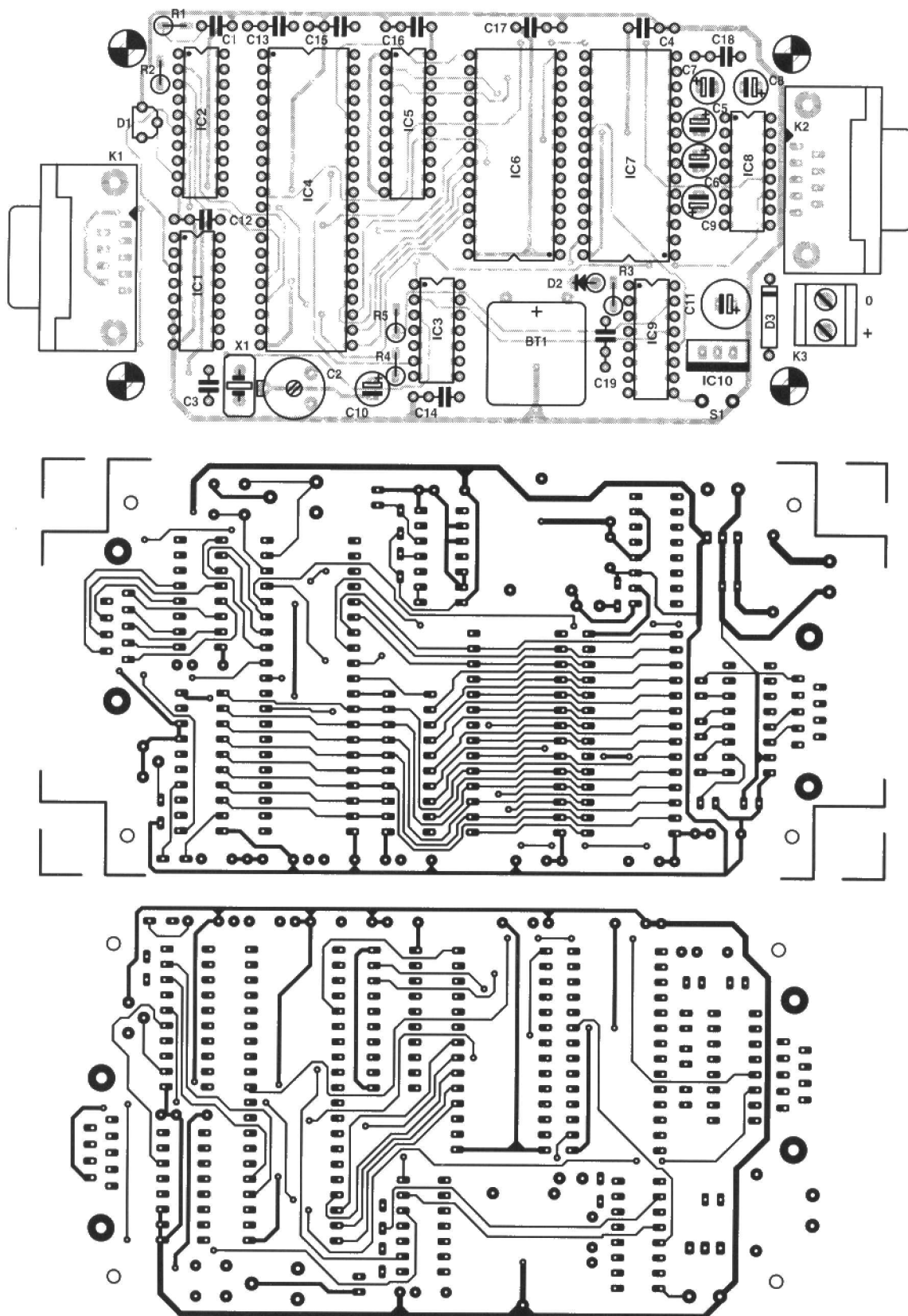


Figure 4. PCB artwork (double-sided board, available ready-made through the Readers Services).

ues of the selected measurement point(s), whose output values are updated every second.

F allows the input of the A-D con-

verter to be scaled. The converter supplies a 0 at 0 V, and 255_{HEX} at +5 V. The default value is F=0.5, which produces a conversion value range of 127.5. F is entered as a four-digit number, which (unusually) includes the decimal point, if used. Negative numbers result in F=0, while leading zeroes are not required.

File Name prompts for a DOS file name to be entered. If no name is entered, an error message is produced when STORE is selected.

Comment enables you to insert any comment which you consider useful in the first line of the measurement file. If no comment is entered, the first line remains empty.

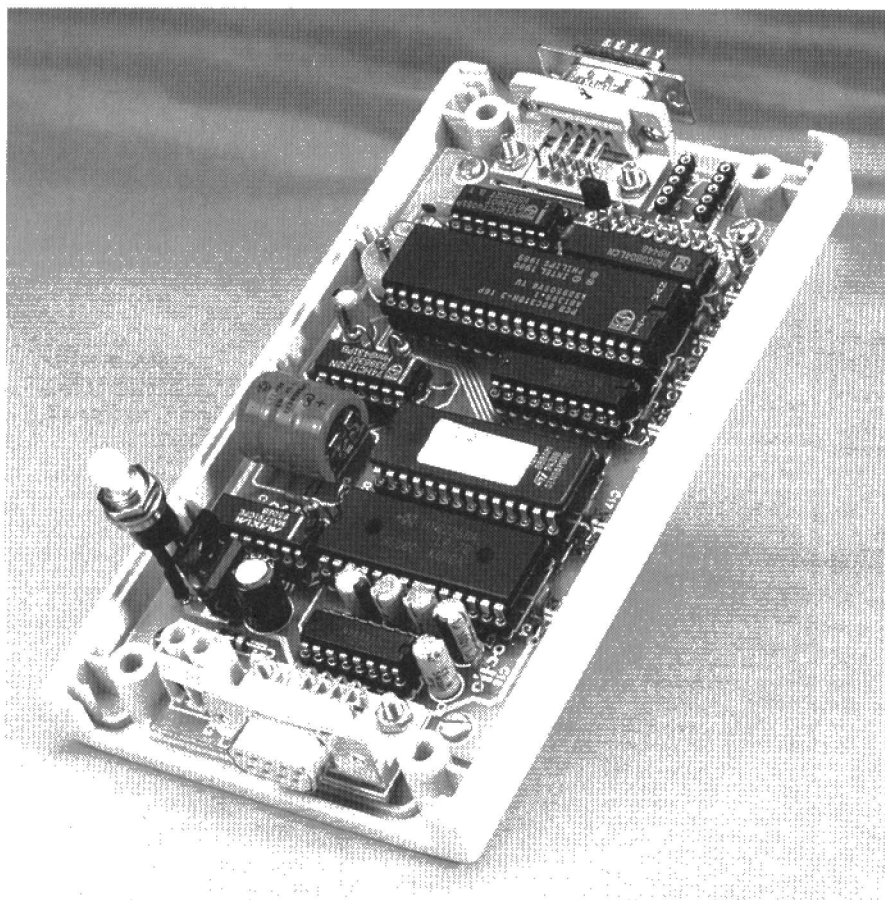


Figure 5. Finished and tested prototype of the datalogger.

At the left-hand side of the screen seven menu options may be seen. They have the following meaning:

STATUS

The display indicates current information on the status of the measurement sequence. Obviously this requires that the datalogger is connected to the PC.

START

The values entered in the right-hand side section of the screen are transferred to the datalogger, and the actual measurement is launched.

STOP

The measurement is halted and can not be continued. The measured values captured so far are not lost, however.

TRANSFER

The measurement data are copied from the datalogger RAM to the memory in the PC.

STORE

The data received from the datalogger are saved (stored) on a disk, using the file format described below. Beforehand, you have to enter a name using file name.

CLEAR

Erase the measurement data in the datalogger.

END

Quits the program after an 'are you sure' prompt.

The format of the file containing the measurement values can be read without problems by data crunching programs like Lotus or dBase.

An example of the file format is shown in **Figure 3**. The file consists of lines, each of which is terminated with a <CR> (carriage return). The first line contains your comment or just spaces.

Each next line starts with the date: day of the month (2 positions), month (2 positions) and year (yes, four positions), all separated by dots. Then, after a space, follows the time, which is displayed using the format [hh:mm:ss]. After another space follow the data for measurement point 1, consisting of five digits (3 digits before, and one behind the decimal point). This pattern is repeated in accordance with the number of measurement points (channels) in use. The data are separated by spaces.

CONSTRUCTION AND ADJUSTMENT

The copper track pattern and component overlay of the double-sided board designed for the datalogger are shown in **Figure 4**. This board is available ready-made in combination with the pre-programmed microcontroller and the control program on disk. For

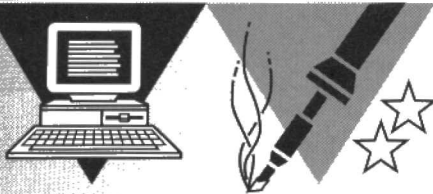
ordering information, please refer to the Readers Services page elsewhere in this issue.

Building up the board should not present problems, mainly thanks to the fact that all ICs may be mounted in sockets. Do note the polarity of the electrolytic capacitors and ICs, however!

Also be sure to fit the right connectors in positions K1 and K2: K1 calls for a 9-way sub-D **plug** (i.e. a male connector), while a 9-way sub-D **socket** (i.e. a female connector) is used in position K2.

The completed board is mounted in a small plastic (ABS) case, which should provide access to the supply socket, the sub-D connectors and, of course, the reset push-button. The latter is preferably mounted in a recessed position, though, to prevent the datalogger being reset by accident.

Because the timing of the datalogger is totally dependent on the microcontroller's clock signal (which is adjusted with C2), you only have to select a measurement interval of 1 s using the control program (1 test point, 1 s), and check the corresponding frequency of 1 Hz at pin 5 of the A-D converter. Alternatively, temporarily insert a 560-pF capacitor between C3 and ground, connect a frequency meter across the 560-pF cap, and adjust C2 to 12.000 MHz at the highest precision you can obtain. Remove the 560-pF cap after this setting. (970059-1)



chipcard reader/programmer

interrogate those flexible friends

A minium amount of hardware is needed to build a chipcard reader/programmer that enables you to use a PC to examine the electronic contents of, among others, telephone cards (interesting stuff for collectors!). Moreover, the circuit allows the user to re-program the non-protected parts of expired chipcards, giving them a new application, for example, in an electronic door lock system.

PARALLEL PORT WORKS IN SERIAL MODE

There's practically no limit to what can be done with the parallel and serial ports on your PC. You may have seen serial interfaces used as quasi-parallel input/output ports. For the present project, we're going to use a parallel port to convey data in serial fashion!

The use of serial data transfer for the present project is not surprising because most of you will be aware of the fact that a chipcard has relatively few contacts (six or eight), of which three are claimed by the ground (GND) and supply connections (V_{cc} and V_{pp} or V_{ss}).

In addition to an input/output line (or just an output in some cases) a chipcard normally has a CLOCK input



and a RESET input, all usually operating at TTL levels (0 V and +5 V).

A parallel port as available on your PC offers an ample number of input and output lines which are perfectly compatible with the said switching levels. In fact, all you have to do is decide which of the two parallel ports on your PC, LPT1: or LPT2:, is free to do the talking with the chipcard reader/programmer described in this article.

As promised, the circuit diagram shown in **Figure 1** is very uncomplicated, in fact it boils down to a number of direct connections between the parallel port lines and the connector on the chipcard.

Some components had to be added, though, and they have the following functions:

- R1 limits the current which may be drawn from the V_{cc} supply when a short circuit occurs as a chipcard is inserted in the connector.
- R2 is a pull-up resistor which is needed with chipcards of the 'open-drain' type. For these cards, the BUSY line of a PC parallel port does not pro-

vide the right resistor value, so a small correction is necessary.

- The function of resistor R3 is similar to that of R1, but then for the programming voltage supply (V_{pp}). This voltage, incidentally, is only used when writing into cards having an NMOS EPROM ('first generation' telephone cards generally known as 'T1G' types in France, and called 'GPM256' by GEMPLUS). By contrast, most of today's chipcards are manufactured in single-supply (5 V) CMOS EEPROM technology.

- C1 and C2 help to decouple the two supply voltages V_{cc} and V_{pp} . These capacitors are essential in view of the fast rising edges of the control signals.

- Diodes D1 and D2 ensure that the V_{pp} connection of any chipcard inserted into the reader/programmer socket is held at 5 V even if no V_{pp} supply is connected. Although the absence of this voltage is tolerated by, for example, TMS3561 chips from Texas Instruments, it disables any reading of ET1001 chips from SGS-Thomson.

- Diode D3, finally, plays an important role with the most recent card types

Design by P. Gueulle

whose DATA line is not just an output, but also an input. The diode allows a low logic level to be forced by actuating the STROBE line on the parallel port, while the logic '1' level corresponds to a 'high impedance' state (D3 blocked). The presence of this diode is particularly indispensable if you want to read or program chipcards which use the I²C protocol.

PRACTICAL REALIZATION

As may be expected, the artwork for the printed circuit board (Figure 2) is limited to a very small number of solder pads and copper tracks, arranged at one side of the board. The chipcard connector (an ITT-Cannon type) and a PCB-style 25-pin sub-D plug are directly fitted on to the board in accordance with the component mounting plan shown in Figure 2b, as are the two terminal blocks for the V_{cc} and V_{pp} supplies.

The large majority of chipcards having the 'ISO' layout from now on, the brush contact configuration for the now obsolete 'AFNOR' type of chipcard (a relic from France) is not implemented. If, in a rare case, you should want to use a card with the chip fitted in the 'AFNOR' position, it is sufficient

to solder eight short isolated wires between the pins with the same name on the connector (1 to 1, 2 to 2, and so on, through 8). This little modification, although rarely required, is surely preferred over designing and etching a

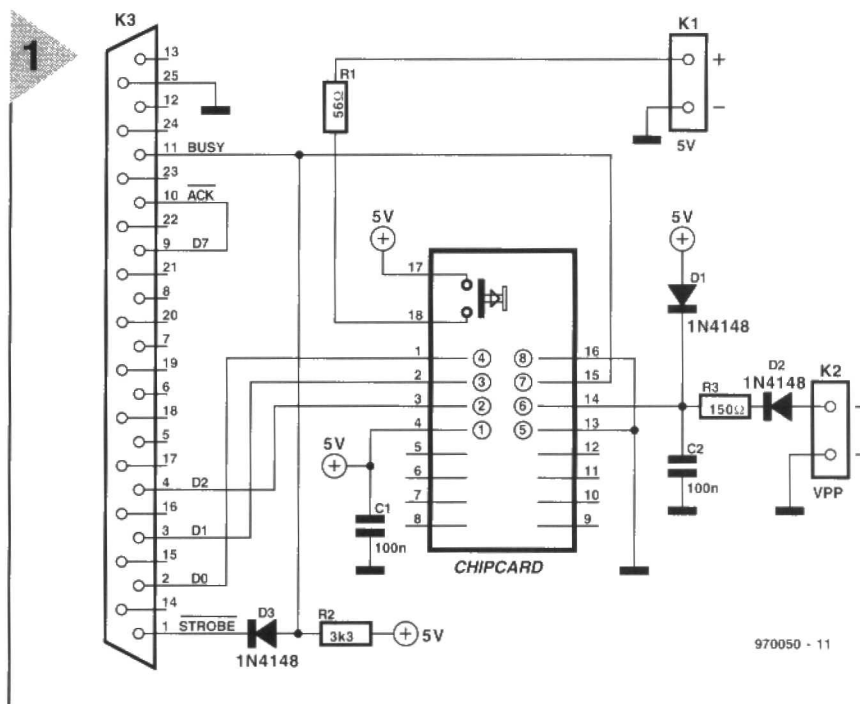
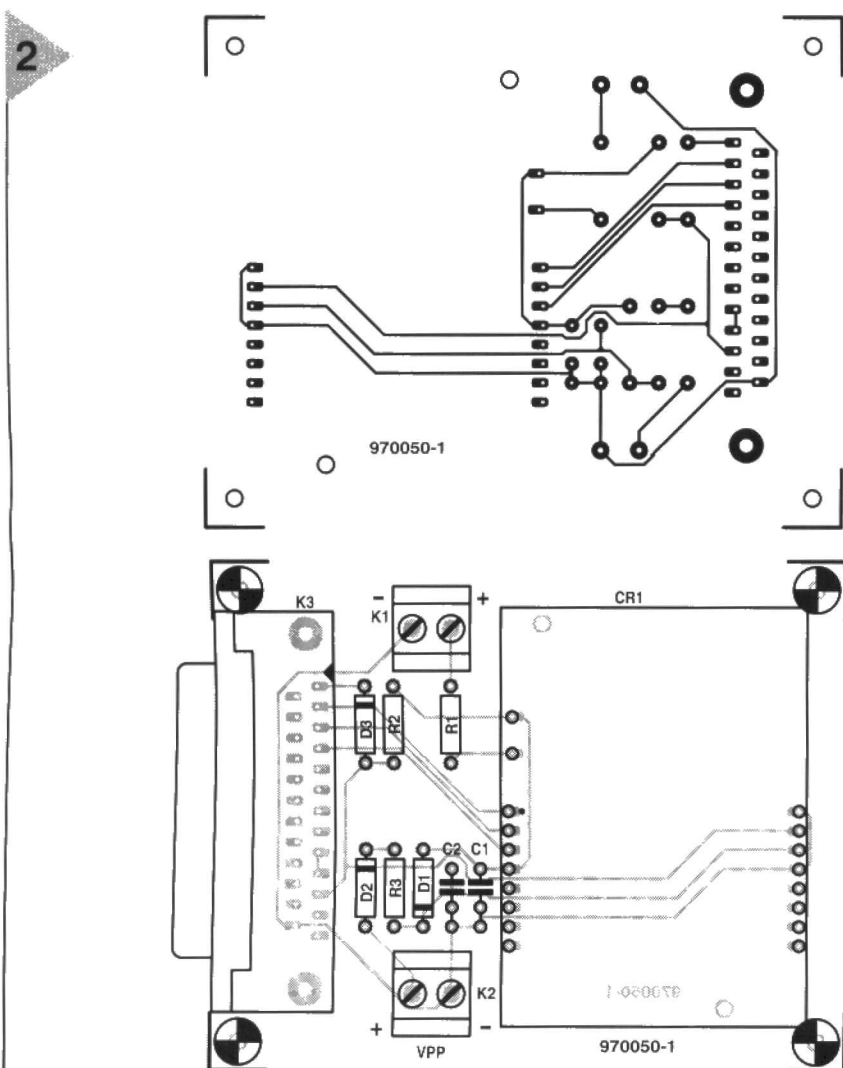


Figure 1. Circuit diagram of the chipcard reader/programmer. The chipcard whose contents you want to examine communicates with the PC via one of the parallel printer ports.



COMPONENTS LIST

Resistors:

R1 = 56Ω
R2 = 3kΩ3
R3 = 150Ω

Capacitors:

C1, C2 = 100nF

Semiconductors:

D1, D2, D3 = 1N4148

Miscellaneous:

K1 = 25-pin sub-D plug, PCB mount
K2, K3 = 2-way PCB terminal block, raster 5mm
K4 = chipcard connector, ITT-Cannon or similar.*
Printed circuit board and software on disk (set), order code 970050-C (see Readers Services page)
Diskette only, order code 976010-1 (see Readers Services page)

* ElectroMail (RS Components), order code 453-751.

Figure 2. Copper track layout and component mounting plan (single-sided) of the printed circuit board designed for the card reader/programmer (board available ready-made through the Readers Services).

Figure 3. Extract from the program routine written for the reading of GPM256 chipcards.

```

\ ----- CARTE.4TH -----
\ ----- READ PHONECARDS USING FORTH -----
100 MSDOS                      \ directive to create .COM file
INCLUDE DISPLAY1.4th

\ declarations:
632 CONSTANT OUT                \ 632 for LPT2: 888 for LPT1:
633 CONSTANT INP                \ 633 for LPT2: 889 for LPT1:
VARIABLE CPT                    \ bit counter for lus
: MAIN                          \ start of main program
SETUP-VID
  0 OUT PC!                     \ no voltage on any of the card lines
  250 OUT PC! 248 OUT PC!      \ RESET card
  8 0 DO                        \ 8 lines for card image
  8 0 DO                        \ 8 blocks of 4 bits for each line
  0 CPT !                       \ first bit
  BEGIN
  249 OUT PC!                   \ one bit output by card
  INP PC@                       \ read bit on parallel port
  128 AND 0=                    \ read BUSY line
  IF 49 EMIT                    \ display a bit which is at 1
  ELSE 48 EMIT                  \ display a bit which is at 0
  THEN 32 EMIT                  \ display space after each bit
  251 OUT PC!                   \ advance card address counter
  CPT @ 1 + DUP CPT ! 3 >      \ counting of displayed bits
  UNTIL 32 EMIT                 \ display a space for every 4 bits
  LOOP                          \ next bit
  CR                             \ return to line
  LOOP
UNSETUP-VID ;
INCLUDE DISPLAY2.4TH
INCLUDE FORTHLIB.SCR           \ load standard FORTH library
END                             \ compile the program
                                \ (c)1995 Patrick GUEULLE

```

double-sided printed circuit board... More information on AFNOR cards may be found in the February 1997 article. Remember, the ISO and AFNOR contact groups may be connected in parallel inside the card reader module.

SETTING UP

Having populated the board and

checked it, you may connect the reader/programmer unit to one of the parallel ports of your PC.

It makes no difference whether you choose to use LPT1: or LPT2: as the programs developed for this project have an internal function which enables them to detect the attached hardware automatically.

Since two parallel ports are usually

available, the most logical choice would be to use LPT2: for the chipcard reader/programmer, and reserve LPT1: for the printer (PRN) which is very useful for producing hard copy of 'card images' displayed on the screen by our programs.

The chipcard reader/programmer is connected to the PC's parallel port using a 25-way cable of the 'extension' type (having a plug at one end, and a socket at the other), or a male-to-male cable in combination with a gender changer.

Either way, you have to ensure that the pins 1, 2, 3, 4, 9, 10, 11 and 25 have a 1-to-1 connection between the cable ends. Certain RS232 cables, in particular those of the 'zero-modem' type, are definitely not suitable!

Although the length of the cable (flatcable or shielded) may be up to 1 metre, some 50 cm will usually be long enough to be able to locate the read/write unit near the keyboard.

The 5-volt supply voltage is readily 'borrowed' from pin 1 of the 15-way joystick connector which is available on most 'multi-I/O' cards. Lacking such a card, your benchtop power supply will do the job equally well. Alternatively, even a 4.5-volt battery may be used.

The supply is only loaded when a card is inserted into the cardreader socket, which has a special detector for this purpose. The V_{pp} supply, by contrast, may only be switched on if the relevant program prompts you to do so by means of a screen message. Of course, the programming supply may also be switched on during your experiments, but only if you know what you are doing! In any case, it **must** be removed before the V_{cc} voltage, in other words, before the card is pulled from the connector. Remember, EPROM memories will **not** survive the presence of the programming voltage (V_{pp}) when there is no regular supply voltage (V_{cc})!

So, you are well advised to use a benchtop power supply set to 21 V (and having an on/off switch). If you want to experiment with card programming, the PSU output voltage is connected to the V_{PP} terminal block pins.

THE CONTROL SOFTWARE

If the present ultra-simple circuit is capable of handling nearly all current chipcards of the 'synchronous' type, you really should not be satisfied with general-purpose software to perform the large variety of experiments offered by the project. We have collected (on a disk) a number of programs, each dedicated to a specific card family: Eurochip and look-alikes, GPM256 and others of the T1G family, French T2G types and similar cards.

Figure 4. The program ELEKEURO.EXE gives you read and write access to the memory of cards derived from the German 'Telefonkarte'. Here, the result of a read operation is shown.

[illegible]

and, finally, I²C chipcards (chiefly the D2000 and D4000 types from Philips).

Also on the disk are a number of utility programs which allow you to start exploring the wonderful world of chipcards, even if you happen to have a totally unknown card: a souvenir from a trip abroad, a bus card, a parking or carwash card, or even a customer identity/discount card you received in a department store. Plain curiosity in this field allows you to discover many things for yourself.

Getting the plethora of functions offered by all card types to work (in particular, writing) calls for loads of information which is not always easy to obtain. Our collection of software utilities is the result of several years of patient research. To illustrate this, **Figure 3** shows the listing of the routine reserved for the reading of GPM256 cards. This program (extract) displays the well established format of eight lines of eight blocks, each consisting of four bits.

The fact that FORTH is used as the programming language may come as a surprise in these days of C++ and Visual BASIC.

The use of FORTH presents a number of advantages for this type of application: to begin with, there's the possibility to produce very fast signals without recourse to assembler code (remember, chipcards may be clocked at frequencies of several MHz).

Even if you are not familiar with the syntax of the FORTH programming language, it is not difficult to discover that the CLOCK and RESET signals for the chipcard are created by manipulating the bits of port 632 (for LPT2:), and that the data produced by the card are read by masking the most-significant bit (value 128 in decimal) of port 633 (i.e., the BUSY line).

EURO CHIPCARDS AND LOOK-ALIKES

The program **ELEKEURO.EXE** on the diskette allows you to perform read and write operations in the memory of chipcards derived from the German 'Telefonkarte'.

Actually, this group not only includes chipcards known under the name 'Eurochip', but also all those of the preceding generation, which are still widely used in lots of applications.

This software exploits the 'normal' functional mode of these cards, thus offering 'sequential' access to their memories.

As soon as a card is inserted and reset (this happens automatically), the first bit in its memory is displayed. You simply press the spacebar to move on to the next bit, with a possibility for auto-repeat if you want to move on rapidly.

Figure 4 shows the results obtained

in this way. It is always possible to have everything printed on paper by doing a 'print screen'.

As you can see, the maximum number of bits that can be read is 512. Although this amount is necessary to fully explore the most recent cards, the address counter may finish much earlier (from the 128th bit for the simplest cards).

Provided the current bit is located in a zone which is not protected against writing, it may be changed to 0 if it is still at 1. This is achieved by pressing the + key on the numerical keypad.

The display readout will not be affected by this because the relevant bit was already read, and it is not possible to make the address counter do another round without resetting it to zero (using the RESET command, or by removing and inserting the card).

Likewise, if you press the - (minus) key on the numerical keypad, you not only change the current bit to 0, but also reset the eight bits of the least-significant (LS) address counter to 1.

Obviously this 'retention' function

number of other countries which have remained faithful to this technology. The same program also reads and writes all other cards having a 256-bit EPROM.

Of course, the area corresponding to the first 96 bits is *forever read-only*, the fuse protecting it having been blown before the card went into circulation. **Figure 5** shows what the working screen of the program looks like. It is much simpler than that of the previously discussed program mainly because these old cards do not have a 'retention' function.

Starting from the 97th bit (start of the fourth line) it is possible to turn any individual bit which is at 0 into a 1. In practice, this type of operation will only apply to the area which remains unused after all phone billing units have been used up, simply because it is unlikely that you wish to lower the 'credit' amount of cards which are still usable...

An interesting possibility for practical use is to 'personalize' expired telephone cards and so enable them to be used for electronic door openers or information security locks.

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Figure 5. The program ELEKT1G.EXE gives bit-for-bit read and and write access to the memory of French '1st generation' telephone chipcards, and all other chipcards having a 256-bit EPROM. Here the working screen of the program is shown; it is rather simpler than the previous one.

space bar : read next bit (auto-repeat)							
+ key : write 1 (current bit)							
ESCAPE key: quit							
1100	0111	0000	0011	0101	0100	0101	0000
1011	1111	0100	0111	1000	0100	0000	0111
1011	1111	1110	1110	0001	0000	0000	0110
1111	1111	1111	1111	1111	1111	1111	1111
1111	1111	1111	1111	1111	1111	1111	1100
0000	0000	0000	0000	0000	0000	0000	0000
0000	0000	0000	0000	0000	0000	0000	0000
0000	0000	0000	0000	0000	0000	1111	1111

WARNING: Switch the V_{pp} OFF!

only works if the current bit is located in another counter than the LS one. In all other cases, the - key has the same effect as the + key.

It is possible to leave the program at any point by pressing the Esc(ape) key, in which case there is no intervening write action.

To begin reading at start of the memory, and view the effects of any previous 'manipulations', all you have to do is launch the program again (for example, by pressing the F3 key).

GPM256 CHIPCARDS AND OTHER T1G'S

The program **ELEKT1G.EXE** enables you to read and write, on a bit for bit basis, the memory of 1st generation telephone cards used in France and a

T2G'S AND DERIVATIVES

The program **ELEKT2G.EXE** is specifically aimed at telephone cards of the '2nd generation' in France (T2G), as well as cards having SGS-Thomson chips using the same technology (ST1331, ST1333 etc.).

What you see in **Figure 6** bears great resemblance to the Eurochip, because a 'retention' mechanism is also available.

The main difference is that 'blank' means a 0 on a T2G card (as with the T1G). Consequently the + key serves to change 0's into 1's.

The - key allows all bits of a counter to be reset to 0, while at the same time a 1 is written in the counter with the next higher significance level.

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Figure 6. The program ELEKT2G.EXE is specifically aimed at telephone chipcards of the '2nd generation' (T2G), chiefly used in France. It can also be used for SGS-Thomson chipcards based on the same technology (ST1331, ST1333 etc.). The similarity with the Eurochip structure is obvious.

space bar : read next bit (auto-repeat)							
+ key : write 1 (current bit)							
- key : write 1 (with carry)							
ESCAPE key: quit							
1000	0001	0100	0000	0010	0000	0000	0001
0100	0001	1001	0000	1001	0000	0000	0101
0000	0000	0000	0000	0111	1111	0000	0111
0111	1111	1111	1111	0001	0000	0001	1001
1111	1111	1111	1111	1111	1111	1111	1111
1111	1111	1111	1111	1111	1111	1111	1111
0000	0000	0000	0000	0000	0000	0000	0000
0000	0000	0000	0000	0000	0000	0000	0000
0111	0101	1111	1111	0000	0000	0000	0000
1111	0101	1111	1111	1111	1111	1111	1111
1111	0101	1111	1111	1111	1111	1111	1111
1111	0101	1111	1111	1111	1111	1111	1111
1111	0101	1111	1111	1111	1111	1111	1111
1111	0101	1111	1111	1111	1111	1111	1111

7

Figure 7. The operation of the read utility ELEKLI2C.EXE differs considerably from the previous programs because sequential reading yields a series of decimal values.

```

171 205 239 0 17 34 51 68 255 255 255 255 255 255 255 255 255 255
255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255
255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255
255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255
255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255
255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255
255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255 255

```

The above data are saved into I²C.ROM

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Figure 8. The utility ELEKTCAR.EXE is the ticket for the more adventurous among you. It can read literally any synchronous chipcard except I²C types (which is easily verified by running LECTI2C.EXE which rejects non-I²C cards). The data extracted from the chipcard by this program indicates that the address counter is reset when it reaches address 512.

space bar : read next bit											
ESCAPE key: quit											
0	(0h)	1010	1000	0100	0110	0011	1011	0001	0000	31	(1Fh)
32	(20h)	0000	0000	0000	0000	0000	0000	0000	0000	63	(3Fh)
64	(40h)	0000	0011	1111	1111	1111	1111	1111	1111	95	(5Fh)
96	(60h)	1111	1111	1111	1111	1111	1111	1111	1111	127	(7Fh)
128	(80h)	1111	1111	1111	1111	1111	1111	1111	1111	159	(9Fh)
160	(A0h)	1111	1111	1111	1111	1111	1111	1111	1111	191	(BFh)
192	(C0h)	1111	1111	1111	1111	1111	1111	1111	1111	223	(DFh)
224	(E0h)	1111	1111	1111	1111	1111	1111	1111	1111	255	(FFh)
256	(100h)	1111	1111	1111	1111	1111	1111	1111	1111	287	(11Fh)
288	(120h)	1111	1111	1111	1111	1111	1111	1111	1111	319	(13Fh)
320	(140h)	1111	1111	1111	1111	1111	1111	1111	1111	351	(15Fh)
352	(160h)	1111	1111	1111	1111	1111	1111	1111	1111	383	(17Fh)
384	(180h)	1111	1111	1111	1111	1111	1111	1111	1111	415	(19Fh)
416	(1A0h)	1111	1111	1111	1111	1111	1111	1111	1111	447	(1BFh)
448	(1C0h)	1111	1111	1111	1111	1111	1111	1111	1111	479	(1DFh)
480	(1E0h)	0110	0000	1011	1111	1111	0011	0010	1011	511	(1FFh)
512	(200h)	1010	1000	0100	0110	0011	1011	0001	0000	543	(21Fh)
544	(220h)	0000	0000	0000	0000	0000	0000	0000	0000	575	(23Fh)
576	(240h)	0000	0011	1111	1111	1111	1111	1111	1111	607	(25Fh)
608	(260h)	1111	1111	1111	1111	1111	1111	1111	1111	639	(27Fh)

It will be obvious that powerful security mechanisms are implemented on these cards to prevent the above operation from being applied to 'charge' expired cards!

I²C CHIPCARDS

By producing the D2000 card (256 bytes) and the D4000 (512 bytes) Philips finally falls in line with the standardized card pinout laid down in the ISO7816 standard. Before the D2000 and D4000, Philips (in a head-strong and non-conformist way) used to market chipcards based on the PCF8582 chip.

The result of this evolution is that our chipcard reader/programmer is perfectly capable of reading and programming the memory of these commercially available cards. These cards are also relatively cheap and have a large capacity (2,048 and 4,096 bits respectively).

The fact that these cards offer

totally free access, i.e., they have no protection whatsoever, neither for reading nor writing, makes them very interesting to us.

As opposed to synchronous ISO7816 cards, I²C chipcards are not accessible on a bit-for-bit basis, but byte-for-byte, in sequential or random fashion.

The upshot is that the operation of the utility to read these cards, ELEKLI2C.EXE, differs considerably from the other programs discussed so far.

Sequentially reading a given number of bytes starting at the first (in most cases, the entire card contents will be read), the program displays data as a set of decimal values (Figure 7), all of which are saved in an ASCII file called I2C.ROM.

The file format, *free format decimal*, is compatible with many conversion utilities, for example, to binary or hexadecimal.

It is, in any case, directly usable by the chipcard write utility on the disk, ELEKPI2C.EXE, which allows you to make a copy of the card in the simplest way you could think of.

It is interesting to note that 'blank'

focus on: modern surround sound systems

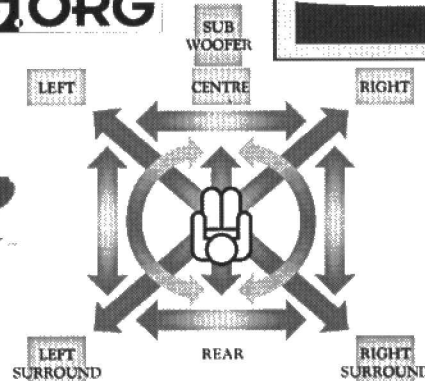
spatial digital sound in the living room

Today there are so many variants of surround sound in circulation that even professional audio engineers find it difficult to keep track of them and the various standards of multichannel audio equipment. In this article we will endeavour to give a pot-
ted history of the system followed by an overview of the latest developments and terms used in the industry, such as AC-3, Virtual Surround, MPEG, Surround 5.1, RSX3D, and associated matters.

By our editorial staff

MPEG.ORG

DVD



**ADVANCED
TELEVISION
SYSTEMS
COMMITTEE**

**DOLBY
DIGITAL**

Digital Satellite Source

INTRODUCTION

From the birth of audio in the 1920s until the 1980s, the formats used in audio systems for film, television, hi-fi, and computers were readily recognizable. The different systems grew and developed independently of one another. Over the past ten years or so, there has been a clear change in this, mainly owing to the development of surround sound.

FROM MAGNETIC RECORDING TO DIGITAL DATA

In the early 1950s, when a new sound dimension, stereo, was introduced and television was becoming serious competition for the cinema, work was already progressing on new wideband film formats (35 mm and 70 mm). During that period, the first commercially applicable multichannel audio systems appeared on the market (at first for use on airports for recording conversations between control tower and aircraft). The various sound channels were stored on film via different magnetic tracks. Cinema projectors were fitted with similar magnetic heads, so that the film sound tracks could be reproduced in the cinema via a number of loudspeakers. The multi-channel audio format comprised a left and a

right front channel, a centre channel, as well as a separate bass and rear channel. Owing to its high cost, this system was little used until the 1970s. In the intervening period, sound technicians experimented with the rear channel, mainly to reproduce background sound.

In consumer audio equipment, two channels were the norm since long-playing vinyl records could not contain more than two channels. True, there was an attempt at four-channel (quadraphonic) equipment, but owing to mutually incompatible coding and decoding systems, coupled with poor marketing, this system did not last long.

Television sound was, until not all that long ago, so poor that even amplifiers from the early 1950s sounded better. Even today, there are more monaural TV receivers on the market than stereo models.

THE VIDEO REVOLUTION

In the mid 1970s, the first consumer video recorders came on to the market. These were intended primarily for recording television programs, but the public soon found that they could be used for copying feature films. This coincidental development became the foundation of a now well-established

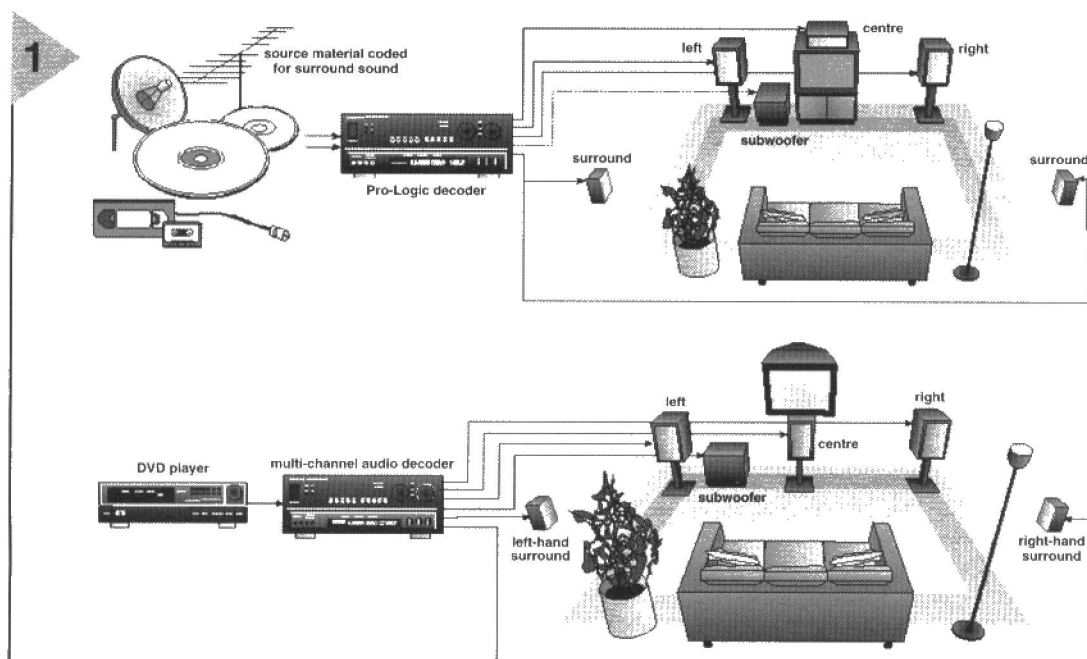


Figure 1. The main difference between Dolby Pro Logic and Dolby Digital is the split drive of the left surround and right surround speakers.

industry for the production, sales, and rental of video cassettes. An initially nervous film industry soon discovered that here was a totally new market for feature films, old and new. This was welcome news, because in those years the cinema was going through a bad patch. (From the early 1980s to the present day, it has, however, been steadily regaining lost ground from television owing to the poor quality of TV programmes and the never-ending repeats). Moreover, it gave the television set in the living room a second function: that of video monitor. Just like sound equipment, the TV receiver could be used with more than one signal source.

In the 1980s, the sound quality of video and TV systems as well as that of the pre-recorded video cassette became immeasurably better. The tinny sound from the TV set that had to be endured until well into this decade became hi-fi stereo sound. It started with pre-recorded video cassettes, but television broadcasting stations soon followed suit. This meant that high-quality audio equipment could also be used for the reproduction of television and video sound.

The sound quality of consumer audio systems had begun to improve in the early 1980s – a process started in Japan. The development by Philips and Sony of the compact disk in the mid 1980s, and new audio systems for use in the car as well as the Sony Walkman¹⁾ radio receivers changed the audio scene, at least in the western world, within a few years.

Young people who have grown up with high-quality audio and video equipment, as well as surround sound in the cinema, are no doubt tomorrow's buyers of high-quality domestic surround-sound systems.

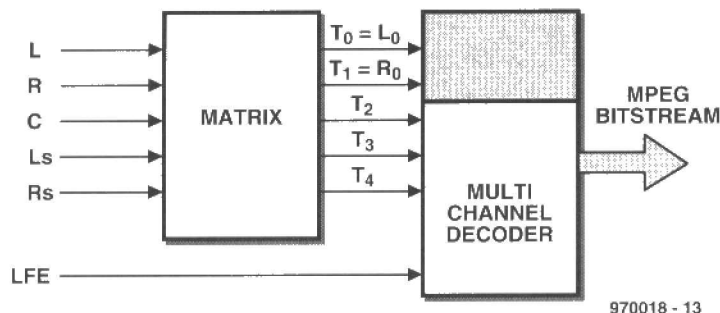
The first domestic surround-sound equipment came on to the market in the early 1980s. At first, this consisted of stereo equipment with an additional rear channel. A little later, when television broadcasters began transmitting stereo sound, Dolby Surround²⁾ and Pro Logic³⁾ added a centre channel. Thanks to the use of digital signal processors (DSPs), it has become possible for the sound quality of domestic equipment to approach that of profes-

sional cinema apparatus. Since the introduction of the Pro Logic decoder, little has changed in the technology. What has changed is the number of television programmes, other than feature films, that are now transmitted in Dolby Surround format. Today, even common sound carriers are often in surround-sound format. Relatively recently, manufacturers of multimedia software products also discovered the merits of surround sound.

The development of surround sound in cinema and consumer equipment

Cinema format	Consumer format
<i>Fantasia</i>	1941
Magnetic tape 35/70 mm (4–6 channel)	1950
	1958 Stereo LP record (2-channel)
	1961 Stereo FM (2-channel)
	1970 Dolby B (noise suppression)
	1972 Video cassettes (monaural)
Optical Dolby stereo (4-channel)	1976
Stereo surround (70 mm magnetic)	1978 Video cassettes (stereo)
	1980 Laser disk
	1982 Dolby surround (3-channel) Compact disk (2-channel)
Dolby stereo spatial (4-channel)	1987 Dolby Pro Logic (4-channel)
Optical Dolby Digital (5+1 channel)	1992
	IC for Dolby Digital
	1993 Dolby Digital standard for digital TV in the USA
	1995 Dolby Digital standard for DVD
	1996 DVD and PC products with Dolby Digital in USA

2



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Figure 2. The coding of up to six channels into MPEG2 data.

THE THIRD GENERATION

In the late 1980s, the Dolby Laboratories developed an alternative to analogue coding. Apart from its two analogue tracks, 35 mm film was enhanced with a digital track located between the perforations. This track contains the infor-

mation for the additional channel, that is, the rear channel. In the analogue system, this channel carried a monaural signal with limited bandwidth. The digital track contains wideband left-hand and right-hand channels.

This new variant of film sound is called 5.1-channel-Dolby. Since its introduction, more than 870 digitally

coded films have already been brought on to the market, while no fewer than 8500 cinemas in 50 countries (as at March 1997) have been fitted with Dolby Digital equipment.

In order to store the large amount of data required for the various chan-

Dolby Digital uses an algorithm for this that has become known under the name AC-3⁴⁾. This set of rules provides substantial data compression without noticeably deteriorating the reproduced sound.

This third generation of audio coding systems from Dolby (after Dolby Surround and Dolby Pro Logic) divides the audio spectrum into narrow frequency bands. The width of these bands is dictated by properties and selectivity of our hearing. This makes it possible for quantization noise to be filtered out. Since the noise signal is also sharply reduced in the absence of audio signals, the final sound quality is (near-) perfect.

The AC-3 system operates over the entire audio spectrum with a dynamic range of 20 bits, for which sampling frequencies of 32 kHz, 44.1 kHz, and 48 kHz are used. The smallest data rate is 32 Kb/s (one mono channel) and the largest, 640 Kb/s. In the 5.1 System, a data rate of 384 Kb/s is reserved for computer applications, and one of 192 Kb/s for two-channel audio.

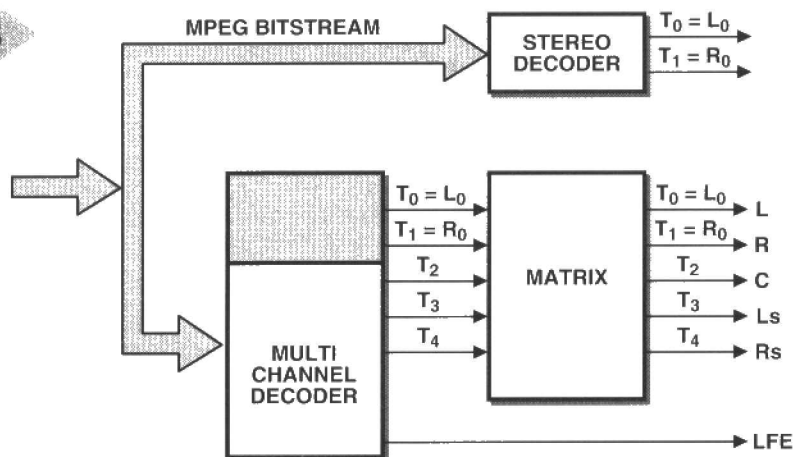
DIFFERENT STANDARD FOR EUROPE

Dolby Standard AC-3 is used only (at least for the present) in North America and Japan. In Europe (where Philips used to set standards although its influence is now waning⁵⁾), a different technology is used: the audio channel from the MPEG2⁶⁾ standard. Note that the video component of this norm has become a world standard for digital television (even in areas where now the NTSC⁷⁾ system is used).

Sony has developed yet another compression technology: ATRAC, but for the time being continues to use MPEG2.

The struggle for an overall standard is, of course, bad news for the consumer. For instance, DVD⁸⁾ players now on the European market are not able to deliver MPEG2 signals to an external decoder: they can play only DVDs with Digital Dolby. Manufacturers have indicated that this will probably not change in the future, since there are no MPEG2 surround decoders available (nor is anyone likely to produce them) and there is also no software with MPEG2 audio in Europe. Even the few DVDs produced in Europe use AC-3 for the 5.1 audio coding (and MPEG2 only for stereo coding to remain compatible with existing MPEG1 decoders). This devel-

3



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Figure 3. During reproduction, the stereo decoder only decodes the MPEG1 component.

opment may well mean that Dolby Digital will become the *de facto* standard for Europe also (which can only be good news for the consumer).

Fortunately, the difference between Dolby Digital and MPEG2 is small as far as the consumer is concerned. Both systems have a left and right front channel, a centre channel and a left and right rear channel. In contrast to analogue systems, all channels cover the entire audio bandwidth. These five channels may be complemented by an optional channel for a subwoofer (20–120 Hz). See **Figure 1**.

The MPEG2 standard is a logical development of the MPEG1 norm for the coding of stereo signals and, thanks to two extensions, MC5+1 and MC7, may be used for the coding and decoding of the 5+1 channels mentioned in the previous paragraph. It also provides for two additional channels (left/centre and right/centre) for use in cinemas that use extra wide screens.

The five input signals are passed through a matrix (see **Figure 2**) whose output signals, T_0 – T_4 , are coded psychoacoustically.

Owing to its limited bandwidth, the subwoofer channel (an extension for very low frequencies) needs only relatively few digital data and is, therefore, applied directly to the multi-channel decoder.

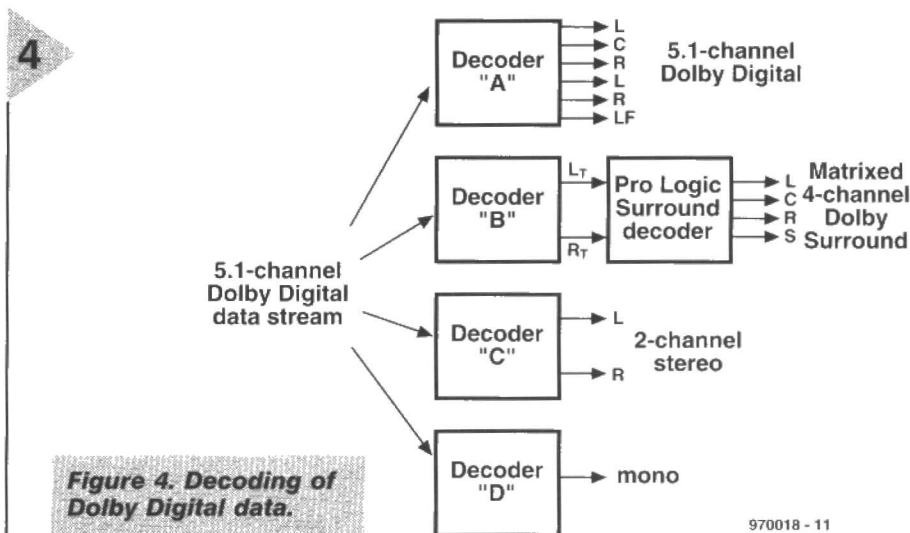
Normally, the MPEG2 data can be applied directly to the carrier. If it is applied to a standard stereo decoder, however, it is decoded as MPEG1 data, that is, as a two-channel stereo signal (see **Figure 3**).

A multi-channel decoder extracts from the data the 5+1 components, whereby T_0 – T_4 are again processed by a matrix.

There are four matrices available to match the signal to the type of decoder to ensure forward and backward compatibility between MPEG1 and MPEG2. (See **Table 1**)

Table 1	Decoder		
Source:	stereo	5+1	7+1
stereo	stereo	stereo	stereo
5+1	stereo	5+1	5+1
7+1	stereo	5+1	7+1

The data necessary for selecting the correct matrix are contained in the MPEG2 signal. In this, it deviates from the AC-3 signal, where the data for the various channels has to be computed (see **Figure 4**). In the case of audio signals with Dolby surround effects, MPEG2 uses a special coding matrix that processes T_0 and T_1 as two Dolby Surround channels. During reproduction, a (two-channel) MPEG1 decoder reconverts the MPEG2 data into a sig-



nal that can be processed by a (Pro Logic) Dolby decoder. Conversely, a multi-channel MPEG2 decoder generates the five channels directly. **Table 2** shows the output signals of the various decoders as a function of the original input signal.

Table 2	Decoder		
Source:	2-channel DVD	5+1	7+1
stereo	stereo	stereo	stereo
surround	surround	surround	surround
5+1	surround/ stereo	5+1	5+1
7+1	surround/ stereo	5+1	7+1

Although Dolby Digital operates slightly differently from MPEG2, and vice versa, **Table 2** shows up few differences. It is, however, a fact that the Dolby system provides better sound quality and channel separation than MPEG2, at least as far as decoding of discrete 5.1 channel and Pro Logic sound tracks are concerned. The same applies to stereo and monaural compatibility.

At the time of writing, there is no clear indication whether the Dolby system or MPEG2 will become the European standard. In the rest of the world, there is little doubt that Dolby will be used. Philips, however, is in deep financial trouble and relies heavily on the North American market where Dolby reigns supreme. It is very important for Philips to secure successful sales of its best product for some time, the DVD (from Polygram).

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More information on the subject of surround sound may be found on Internet homepages:

<http://www.dolby.com>
<http://www.mpeg.org>

¹⁾ Registered trade mark (Sony) of small, portable radio/cassette recorder with headphones for personal use while walking or travelling.

²⁾ Dolby Surround is the logo of the eponymous system developed by the Dolby Laboratories in the early 1980s.

³⁾ Dolby's registered trade name for an analogue surround sound system for consumer use, providing front, centre, and rear speakers.

⁴⁾ Dolby's trade name for the digital audio coding used in 35 mm motion picture film to provide six-channel surround sound. It uses data blocks recorded optically between the perforations, leaving space for a conventional soundtrack. It is also suitable for multi-channel television audio, as well as video software and home cinema.

⁵⁾ According to a recent report in *The Economist*, one of the world's leading business journals, if Philips were not protected by a voting structure that gives absolute power to a few shareholders, the company would have been swooped on some time ago by a corporate raider. See also *Short Circuit: the Decline of a Once Great Company* by Marcel Metz, Minerva Press.

⁶⁾ Acronym of Motion Picture Experts Group, based in the USA, but with offices in Europe, which is a body that produces standards for compressed digital video signals.

⁷⁾ Acronym of the US National Television System Committee, and the colour TV system so standardized.

⁸⁾ Acronym for Digital Video (or Versatile) Disk which many believe will mean the end of the road for the Compact Disk (CD), the CD-ROM (CD-Read Only Memory), and the VCR (Video Cassette Recorder) within the next ten years.

With the rebirth of thermionic valves (electron tubes) in audio amplifiers (note that they never 'died' in radio transmitters), it was felt that some (older) readers would appreciate a nostalgic reminder of what valves were like. Younger readers, not acquainted with valves at all (or very little) will, no doubt, be interested in what those funny glass (or metal) tubes are all about. Thermionic valves for use in audio circuits comprise diodes, triodes, tetrodes, beam tetrodes, and pentodes.

by J. Boersma

thermionic valves: a brief introduction

Fundamentals and operation



The diode is normally used for rectifying small audio frequency (a.f.) signals and, in the power supply, for converting the alternating voltage from the mains into a direct voltage.

The triode is used primarily as a pre-amplifier and phase inverter.

The tetrode, and beam tetrode, is used chiefly as a power amplifier.

The pentode finds application in both preamplifiers and output amplifiers.

The symbols of these various types of valve are shown in **Figure 1**.

The terminology of valves is at first sight confusing, although it is in many ways far more logical than that of semiconductors and integrated circuits. The

first letter in European terminology or digit(s) in American type coding indicates the heater voltage; for instance, E = 6.3 V. Subsequent letters indicate the type of valve. Digits following the letters are manufacturers' series indications. The table in the box gives the meaning of some letters used in valve type coding.

Often, letters are used several times, or several letters are used, for instance, a GZ34 is a full-wave rectifier with a 5 V heater, an ECC83 is a double triode requiring 6.3 V heater voltage, a UCH81 is a triode-heptode needing a 19 V heater supply, and a 6K6 is a beam power tetrode with a 6.3 V heater.

construction of valves

Valves used in audio amplifiers generally have two or more electrodes: cathode, anode, and grid(s).

Cathode and heater

When valves were young (1900–1920), they had a directly heated (called filamentary) cathode. The material of this element, tungsten or nickel, was chosen for the properties that made it suitable for this purpose. Such a construction had some practical drawbacks. For instance, the cathode tended to sag, which meant that the distance between it and the anode varied, which, of course, gives a poor performance. At the same time, the heater was fed by direct current, which does not produce an evenly distributed electron emission to the anode. Supplying the heater with alternating current (a.c.) gave some improvement, but made the temperature of the cathode, and thus the electron emission, vary with the frequency of the current. All these factors meant that the anode current varied widely.

Later, from the early 1920s in the USA, and from the late 1920s in Europe, indirectly heated cathodes became the norm. Such a cathode consists of an oxide-coated cylindrical sleeve, which contains (but is isolated from) the filament. The cylinder is usually made of nickel, while the coating, that is, the source of electrons, is barium or strontium.

The filament heats up when a current is passed through it, which causes the cathode to attain a temperature of 1000–1300 °C. This high temperature

causes the electrons in the coating to attain enough thermal energy to overcome the forces at the surface and escape. Note that in modern valves for use in a.f. equipment the filaments are normally fed by a direct current to eliminate any risk of hum.

Anode

In early valves, the anode was simply a small metal plate (the anode was then, and still is in the USA, called 'plate'). It was soon realized, of course, that this was not a very efficient construction. The anode in modern valves is a rectangular or cylindrical tube, which gives it a much greater surface area. Materials used for anodes are copper, molybdenum, tungsten, nickel, or cupra-nickel.

Grids

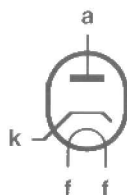
Grids are conductors, semitransparent to electrons, usually in the form of meshes or parallel bars. The material they are made from is usually molybdenum, tungsten or pyrolytic graphite. Various coatings, such as a gold, are used to reduce primary emission.

Although a valve may have many grids, in this brief article only three will be considered: control grid, G_1 , screen grid, G_2 , and suppressor grid, G_3 .

Assembly

Valves are invariably assembled in an evacuated (to 10^{-9} atm.) glass (sometimes metal) tube. The centre is normally formed by the cathode, with in it the filament, then the grid(s), and finally the anode, all cylindrical in shape. All

diode



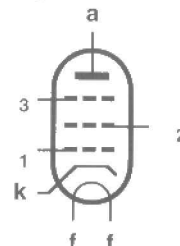
triode



tetrode



pentode



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Figure 1. Symbols for diode, triode, tetrode and pentode. The control grid is G_1 , the screen grid is G_2 , and the suppressor grid is G_3 .

electrodes are sintered on to FeCr alloy pins, which are passed through a mica or ceramic disc. The alloy has the same coefficient of expansion as glass. The mica or ceramic disc is clamped into the base of the tube, which is then evacuated.

Many valves are provided with a conducting coating on the inside of the glass envelope to prevent the wall from acquiring a positive charge through secondary emission.

Also, many valves have a getter which maintains the high vacuum during the life of the valve. They are so called because they 'get' (that is, trap) any gases that may evolve. Getters (potassium, sodium, magnesium, calcium, and others) are evaporated in the valve, after this has been sealed upon evacuation, by high-frequency induction currents.

operation

It is not possible to say with certainty when the development of the thermionic valve began. Undoubtedly, the not very systematic observations of gas discharge phenomena were as important as many accidental discoveries in physics research during the last few decades of the 19th century.

Researchers at the Western Electric Company in the USA found in 1905 that placing a third electrode (the control grid) between cathode and anode of a valve gave a means of controlling the electrons between these electrodes. This first ever triode was called VT1 (= vacuum tube 1).

Diode

Operation of a diode depends on the property that electrons flow from cathode to anode. It was discovered almost a hundred years ago that this phenomenon could be used for rectifying purposes. At the onset of the diode characteristic, the diode current, I_D , does not rise at the same rate as an

increase in the applied voltage, V_D (see **Figure 2**). When the voltage is further increased, the current rises more rapidly, but then levels off when the voltage is increased still further.

Diodes should normally be used only over the straight part of the characteristic; outside this, the distortion rises rapidly.

This situation is also clear in the V_D/I_D characteristic of the EZ81, a full-wave rectifier for use in power supplies—see **Figure 3**. Part of this curve is shown as a dashed line to indicate that in certain circumstances the continuously drawn current must not exceed this value. Of course, the maximum permissible power dissipation in the tube also plays a role.

A specific property of the EZ81, and also of a similar diode, the GZ34, is that the time needed for heating their cathode is longer than that of amplifier valves in the same series. This ensures that the amplifier valves do not get a high anode voltage before they have heated up properly.

Triode

A triode is a diode with a control grid, G_1 , inserted between cathode and anode. An alternating voltage (signal) applied to the grid is found back amplified at the anode. The control grid is invariably negative w.r.t. the cathode (see **Figure 4**). This is often effected by a cathode resistor (which may or may not be decoupled). It causes a positive variation between cathode and anode. The V_D/I_D characteristic of a triode is not as linear as that of a diode. This means that a triode is normally operated in Class A, certainly so if it serves as an output amplifier. Note that because of this an EL84 configured as a triode has a much better linearity than an EC92 or ECC83.

Tetrode

A tetrode has an additional grid, the

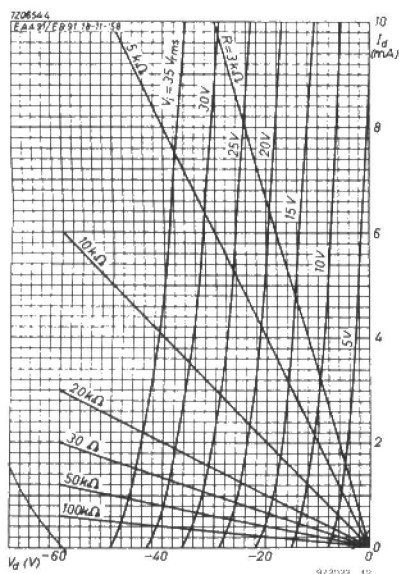


Figure 2. V_D/I_D characteristic of a Type EB91/1/2 EAA91 half-wave rectifier diode. Only operation in the linear part of the curve gives low distortion.

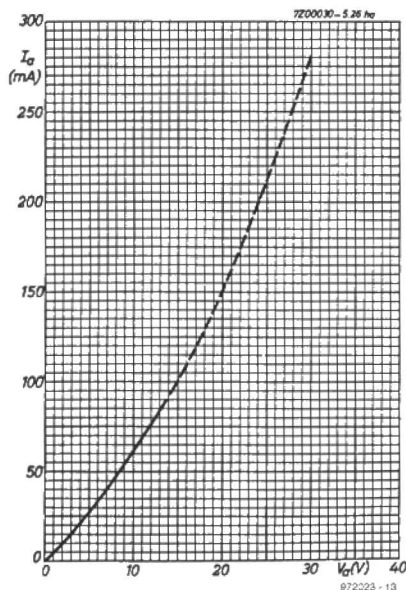


Figure 3. V_a/I_a characteristic of a full-wave rectifier diode Type E281. This valve is intended primarily for use in power supplies.

screen grid, G_2 , between control grid, G_1 , and anode. The function of this additional grid is to reduce the G_1 -anode capacitance. When this capacitance is high, the relative large variations in V_a may induce appreciable variations in V_{G1} . If the phase relations are correct, this induced grid voltage may add to the impressed anode voltage in such a way as to cause the amplifier to oscillate.

Note that the V_a/I_a characteristic of a tetrode is very similar to that of a pentode, but is non-linear at low V_a and low I_a .

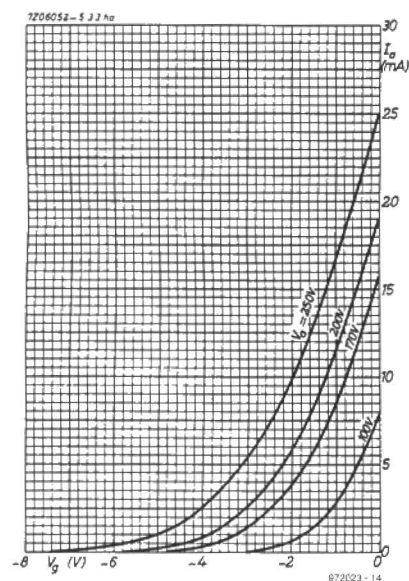


Figure 4. V_{G1}/I_a characteristic of the EC92/1/2 ECC83 triode. Note that the control grid is negative w.r.t. the cathode.

Pentode

Because of its superior performance compared with a triode, the pentode is the most frequently used thermionic valve. In particular, its linearity is much better than that of a triode. A pentode is eminently suitable for Class AB operation in output amplifiers. The V_{G1}/I_a and V_a/I_a characteristics speak for themselves—see Figures 5 and 6.

Moreover, pentodes generally have a much better G_1 -anode transconductance (= mutual conductance), g_m , than triodes. This means that the control voltage for full drive is appreciably lower than that needed by a triode.

Special valves

The Type KT88 beam-power tetrode offers a considerable improvement in the distortion characteristic of the output pentode, while retaining the greater efficiency of that valve compared with the output triode. The special construction of the screen grid ensures a much steeper I_a curve at low V_a , and the transit to the horizontal part is more rapid.

There are so-called Special Quality versions of certain valves, in which better-quality materials for the various electrodes have been used. This ensures a typical life of 10 000 hours. They are distinguished from standard valves by a different arrangement of the type number; for instance, E83CC instead of ECC83 or E84L in place of EL84.

[972023]

Interested readers may find the following books useful.

1. Build your own Audio Valve Amplifiers by Rainer zur Linde; Elektor Electronics (Publishing), 1995
2. Mullard Tube Circuits for Audio Amplifiers; Audio Amateur Press*, 1993 (reprint)
3. Principles of Electron Tubes by Herbert J. Reich; Audio Amateur Press*, 1995 (reprint)

In the United Kingdom, valves and appropriate sockets, as well as other relevant components are available from a number of stockists, among them:

Circuit Distribution, Park Lane, Broxbourne, Herts EN10 7NQ. Phone 01992 448899; fax 01992 471314

Hart Electronic Kits, 7 Penylan Mill, Oswestry, Shrops SY10 9AF. Phone 01691 652894; fax 01691 662864

Readers in other countries may find the following booklet available from Audio Amateur Corporation* useful: World Tube Directory, the world's only complete source book on

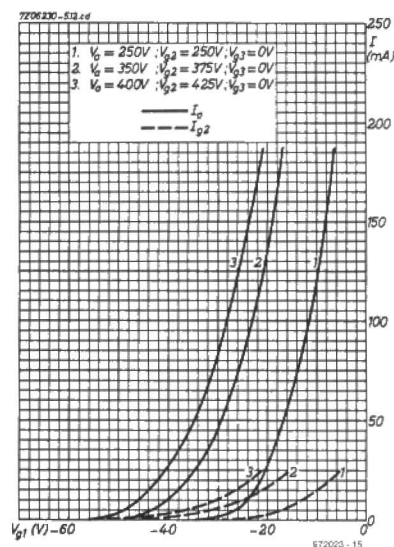


Figure 5. V_{G1}/I_a characteristic of a Type EL34 pentode – note the improvement over that in Figure 4.

vacuum tubes and associated components and relevant distributors throughout the world.

* Audio Amateur Publications, Inc., P O Box 243, Peterborough, NH 03458-0243, USA. Phone 603 924 6371 Fax 603 924 9467

Valve nomenclature

- A = 4 V heater voltage*
- B = diode
- C = triode
- D = directly heater valve
- E = 6.3 V heater voltage*
- F = r.f. pentode
- G = 5 V heater voltage*
- GC = glass container
- H = heptode/hexode
- K = tetrode or beam tetrode
- L = a.f. output pentode
- M = tuning indicator
- Q = high-power beam tetrode
- U = miscellaneous heater voltage*
- VT = vacuum tube
- Y = half-wave rectifier
- Z = full-wave rectifier

* In American type coding, digits are used to indicated heater voltage, for instance, 1 (for 1.4), 4, 6 (for 6.3) 12, 40, and so on.

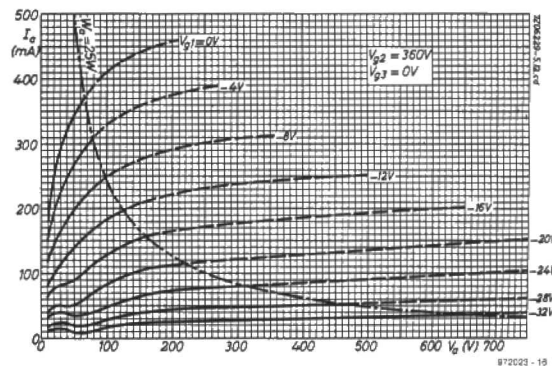


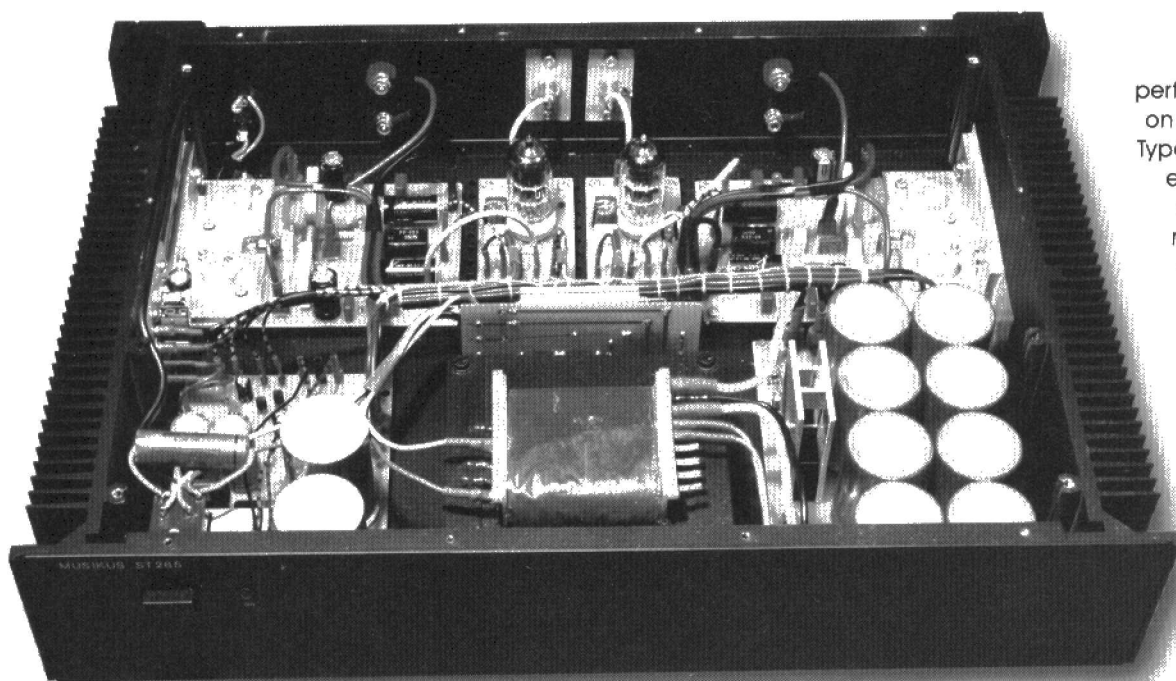
Figure 6. The V_a/I_a characteristic of the EL34 also looks good.

There is no single answer to the question of whether audio amplifiers using transistors are better than those using valves or vice versa. It all depends on the application. Valve amplifiers are undoubtedly better as regards dynamic range, which has to do with the more gradual change in the operating characteristics, which in the case of transistors tends to be abrupt. An attractive compromise is a hybrid amplifier: valve input stages and transistor output stages. This results in an amplifier that offers the best of both worlds.

Design by E. Wincek

hybrid audio amplifier

the best of both worlds?



performance. It is based on a double triode Type PCC88, which has excellent transconductance and requires relatively low anode voltages.

The current (power) amplifier is based on MOSFET transistors which in operation are reminiscent of valves and have a very high input impedance. These transistors are configured as source followers. Their gate voltage is held

stable by constant-current sources and zener diodes.

The result is

Whatever the merits or drawbacks of valve and transistor audio amplifiers, because of their design and nature valves lend themselves much better to voltage amplification and transistors to current amplification. In output stages, which are current, or rather power, amplifiers, valves have a further drawback in that they require an output transformer whose price is directly proportional to its quality. In view of this, the present circuit is a hybrid: it uses valves

in the voltage amplifier and MOSFET transistors in the current amplifier.

The voltage amplifier is configured as a series-regulated push-pull (SRPP) circuit, which provides high amplification and high-quality

Technical data

Input sensitivity for full drive
Input impedance
Power output for full drive

Gain at 1 kHz
Damping factor at 1 kHz
Frequency response:

900 mV
100 k Ω
2.65 W
25 dB
3.2
0 dB
-1.7 dB
1 kHz sine wave into 4 Ω
10 Hz
100 kHz

an excellent, interesting amplifier that is also fairly easy to build. There are only one valve and two transistors in the signal path. Its tone quality is very good and its power output is sufficient to make the neighbours run for the telephone if the volume were turned up full. Because of the high input impedance, CD players with their high output signal can be coupled directly to the amplifier via a 47–100 k Ω stereo potentiometer.

voltage amplifier

The circuit diagram of the SRPP

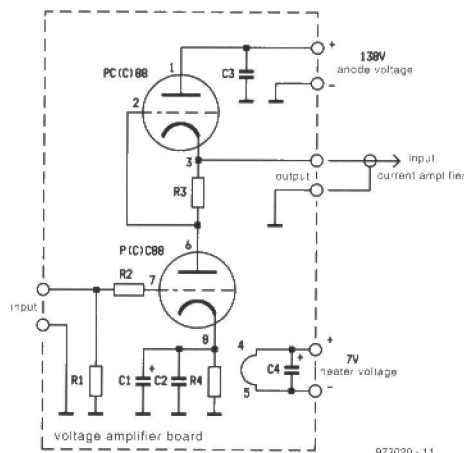


Figure 1. The voltage amplifier board contains, apart from the PCC88, only a few components.

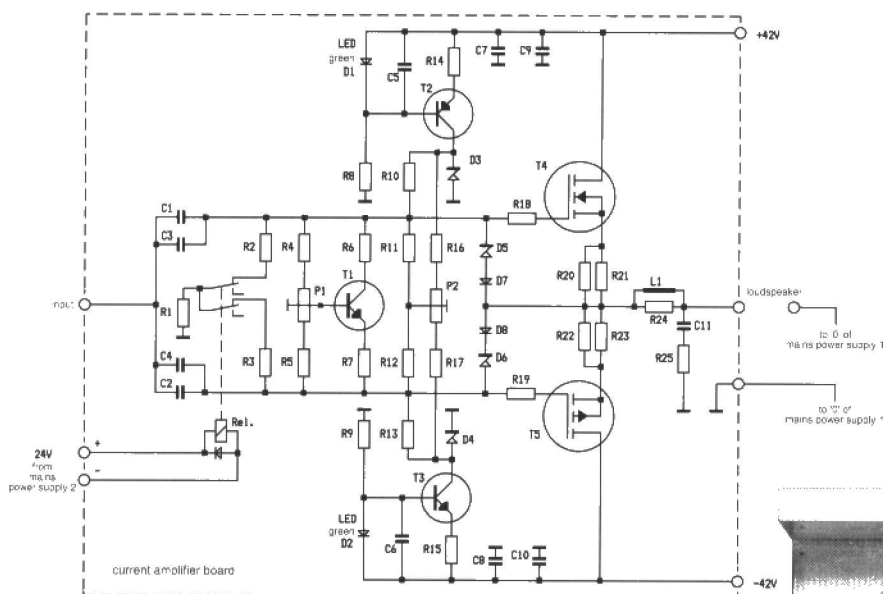
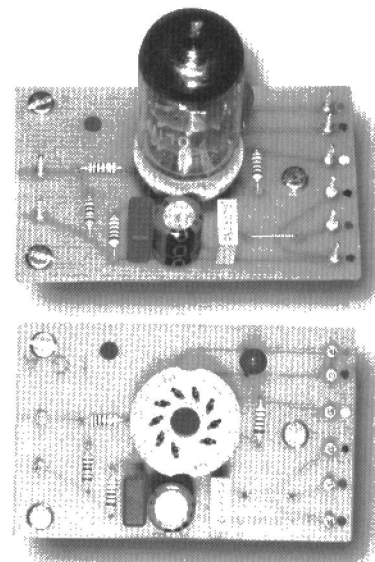


Figure 2. The output amplifier is based on MOSFETs.

voltage amplifier is shown in **Figure 1**. As stated earlier, it uses a double triode Type PCC88. The input is direct coupled (DC) and has an impedance of about 100 k Ω (R_1). An anode voltage of 130–140 V is fine: ideally, it should be 138 V, but not exceed 150 V. Each heater requires a voltage of 7 V: since the two heaters are connected in series, the overall heater supply should be 14 V. The connections to the heaters are decoupled by 10 μ F tantalum capacitors. The anode of the second triode is also decoupled, in this case by a 0.047 μ F polyester type (C_3).

current amplifier

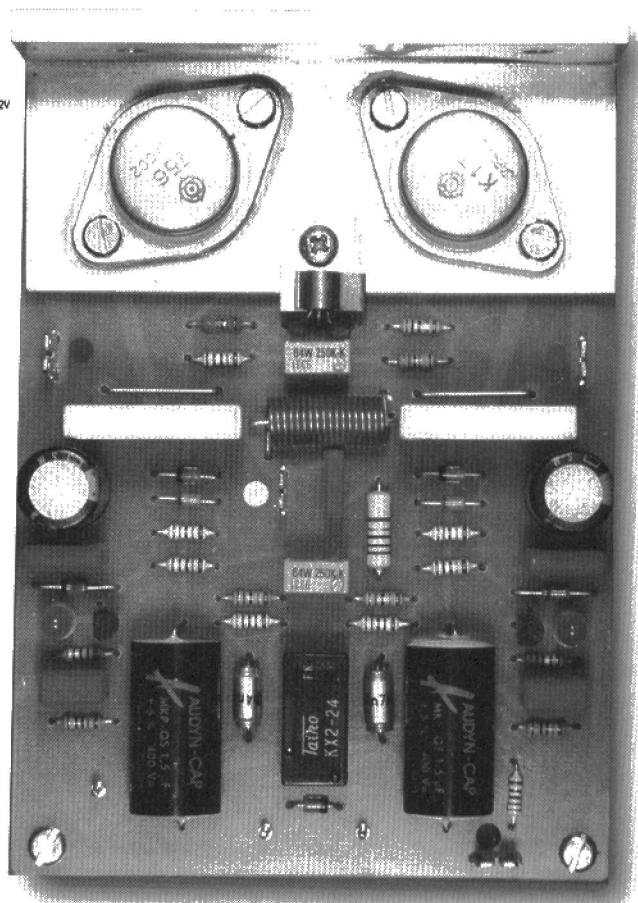
The circuit diagram of the current amplifier is shown in **Figure 2**. It is based on transistors T_4 and T_5 , Type

2SK176 (or 2SK175) and Type 2SJ56 (or 2SJ55) respectively. If the supply voltage is lowered to ± 30 V, and an output power of 50 W is acceptable, Types IRF530/IRF9530 and IRF540/IRF9540 respectively from International Rectifier may also be used to good effect.

Input capacitors C_1 and C_2 are polypropylene (MKP) types, which are shunted by polyester capacitors C_3 and C_4 respectively. In the quiescent state, these capacitors are linked to earth via resistors R_1 – R_3

and the relay contacts. The relay trips after about 20 s, when the capacitors are fully charged so that they cannot cause voltage jumps at the output.

The audio signal is applied to the gates of the MOSFETs via the input capacitors and R_{18} and R_{19} respectively. Transistors T_2 and T_3 operate as constant-current sources and ensure stable direct-voltages at the gates. The gate biases are made symmetrical with P_2 . The quiescent current is



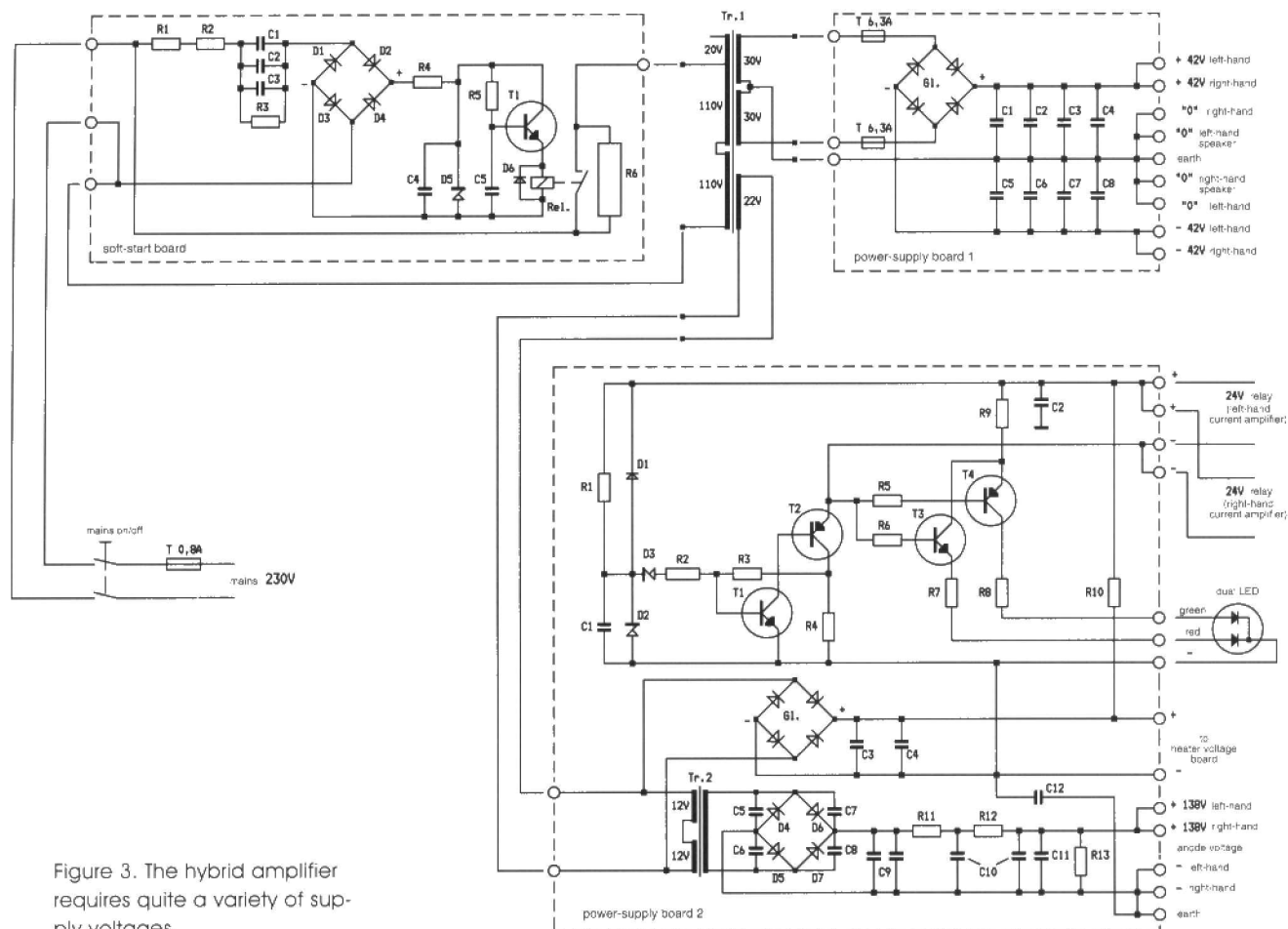


Figure 3. The hybrid amplifier requires quite a variety of supply voltages.

set with P_1 . Protection diodes D_5 – D_8 prevent the gate voltages becoming prohibitively high.

Note that the values of resistors R_{18} and R_{19} in the gate lines are not equal. This is because of the divergent input capacitances of n-channel and p-channel MOSFETs. These resistors are not fitted on the relevant board, but must be soldered directly to the relevant gate.

The source resistors, R_{20} , R_{21} , and R_{22} , R_{23} , each of $0.47\ \Omega$, may be replaced by single resistors of $0.25\ \Omega$ in the R_{20} and R_{22} positions on the board.

Inductor L_1 in the output line is fitted

around resistor R_{24} . It consists of 20 turns 1 mm dia. enamelled copper wire, wound on a 10 mm dia. drill bit.

Network R_{25} – C_{11} is a Boucherot filter.

power supply

The power supply whose circuit diagram is shown in **Figure 3** consists of five parts. The first of these is situated ahead of the mains transformer and provides a soft start for the output stages and prevents the fuses from blowing owing to a high switch-on current. This current is limited during the first few seconds after switch-on by R_6 .

The mains voltage is applied to a bridge rectifier via R_1 , R_2 and C_1 – C_3 (which can be discharged via R_3) and then to a 15 V voltage regulator.

Capacitor C_5 is charged via R_5 and after about 2 s reaches a potential that causes T_1 to switch on, whereupon the relay trips. The relay contacts then short-circuit R_6 .

Mains transformer Tr_1 has three secondary windings: $2 \times 30\ V$ and $1 \times 22\ V$. The voltages across the 30 V windings are applied to a bridge rectifier which provides the $\pm 42\ V$ sup-

ply lines for the current amplifier.

The potential across the 22 V winding is applied to a second transformer, Tr_2 , and then to two bridge rectifiers. This section (on the power supply board) provides the heater voltages and the anode voltages for the voltage amplifiers, as well as the operating voltage for the relay on the current amplifier board (Figure 2) via a delay circuit.

The delay circuit is based on a Schmitt trigger formed by T_1 and T_2 . Capacitor C_1 is charged via R_1 until the potential across it is 10 V. When that level is reached, D_3 comes on, the Schmitt trigger changes state, and the relay on the current amplifier board trips. The relay contacts then link the output of the voltage amplifier to the input of the current amplifier.

The dual LED on the front panel indicates the state of the relay. At switch-on, T_2 is off, so that its collector, and consequently the bases of T_3 and T_4 , carries the full supply voltage. This results in T_3 conducting, whereupon the red part of the LED lights, whereas T_4 remains off. After about 20 s, the Schmitt trigger changes state, whereupon T_3 goes off and T_4 conducts. This causes the red section of the LED to go out while the green one lights to show that the circuit is operational. When the

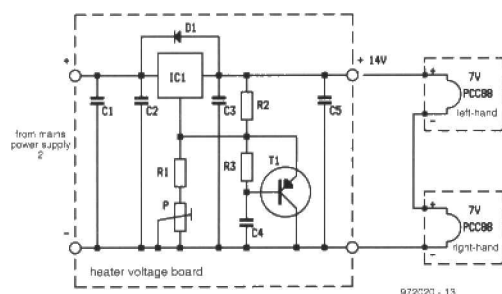


Figure 4. The heater voltage for the PCC88 is regulated. However, it is more important that the heater current is 300 mA.

supply is switched off, C_1 is discharged via D_1 . Resistors R_9 and R_{10} and capacitor C_2 decouple the supply lines to the relay.

The 22 V secondary of Tr_1 is linked to the secondary winding of Tr_2 . Since the current drawn by the two valves does not exceed 5 mA, the rating of this transformer (150 mA) is more than adequate. The voltage across the primary is some 130 V, which is rectified by D_4 – D_8 and smoothed by C_9 and C_{10} . Capacitors C_5 – C_8 and C_{11} are anti-interference devices. When the supply is switched off, electrolytic capacitors C_9 and C_{10} are discharged via R_{13} .

The –ve line of the unregulated heater voltage (about 24 V) is connected to earth not directly but via C_{12} .

The 'raw' heater voltage is applied to a variable, integrated voltage regulator, IC_1 , on the heater voltage board (**Figure 4**). Transistor T_1 provides a gradual increase in the voltage supply to the heaters. The voltage regulator needs a small heat sink.

construction

The stereo amplifier consists of eight printed-circuit boards (see **Figure 5**), which are not available ready made. All boards are provided with suitable PCB connectors to facilitate their inter-connection. Those for the mains power supply and on the current amplifier board have 6.3 mm dia. pins, all others have 1.3 mm pins.

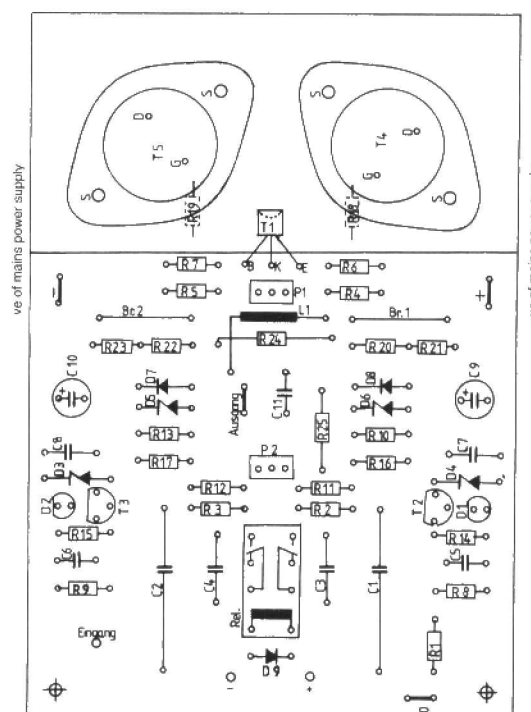
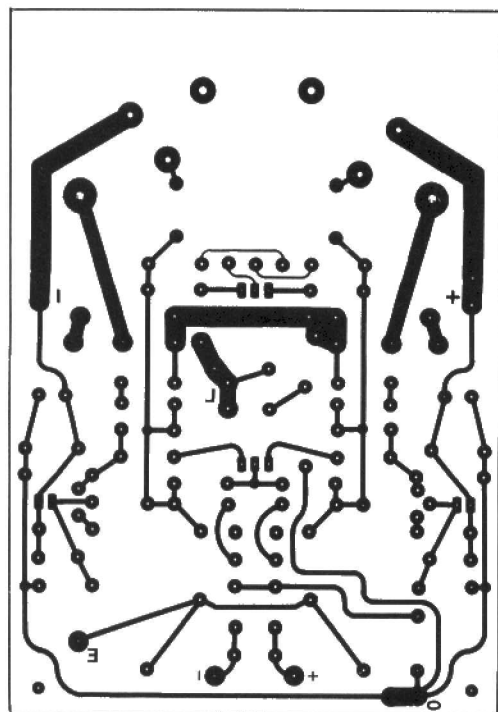
It is imperative that the –ve lines on

all boards are kept separate and are strapped to earth at only one spot on the enclosure so as to prevent earth loops.

The connections to the input and output of the voltage amplifier must be in single screened cable with the screen connected to earth only on the voltage amplifier board.

Consequently, the current amplifier board has no pin for connecting the screen of the input lead from the voltage amplifier.

The MOSFETs and T_1 must be screwed to, but isolated from, an aluminium bracket that links the board and the heat sink for these devices (do not forget ample use of heat conducting paste).



Current amplifier board:

T_1 , R_2 , R_3 = 160 Ω
 R_4 = 680 Ω
 R_5 , R_{16} , R_{17} = 750 k Ω
 R_6 = 10 Ω
 R_7 = 22 k Ω
 R_8 , R_9 = 10 k Ω
 R_{10} , R_{13} = 820 k Ω
 R_{11} , R_{12} = 180 k Ω
 R_{14} , R_{15} = 200 Ω
 R_{18} = 680 Ω
 R_{19} = 510 Ω
 R_{20} , R_{21} – R_{23} = 0.47 Ω , 5 W

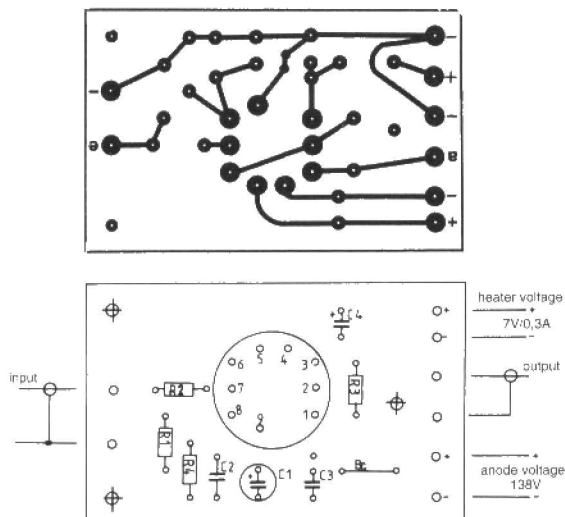
R_{24} = 5.1 Ω , 1 W
 R_{25} = 10 Ω , 1 W
 P_1 , P_2 = 250 k Ω , potentiometer for board mounting, upright

C_1 , C_2 = 1.5 μ F, 250 V, metallized polypropylene (MKP)
 C_3 , C_4 = 4.7 μ F, 160 V, metallized polyester (MKT)
 C_5 , C_6 = 0.68 μ F, 63 V
 C_7 , C_8 = 0.22 μ F, 100 V
 C_9 , C_{10} = 330 μ F, 63 V, radial
 C_{11} = 0.022 μ F, 100 V

D_1 , D_2 = LED, 5 mm, green
 D_3 , D_4 = zener, 15 V, 1 W
 D_5 , D_6 = zener, 12 V, 500 mW
 D_7 , D_8 = 1N4148
 T_1 = 2SC1775
 T_2 = BC560
 T_3 = BC550
 T_4 = 2SK176 or 2SK175 (see text)
 T_5 = 2SJ56 or 2SJ55 (see text)

L_1 = see text
 Re_1 = 24 V miniature relay, 2 make contacts, coil resistance 1400 Ω

Figure 5. Layouts of the various PCBs used in this design. Two voltage amplifier boards and two current amplifier boards are needed for a stereo amplifier. Note that there is no board for the mains power supply.



Voltage amplifier board:

$R_1 = 100 \text{ k}\Omega$

$R_2 = 1 \text{ k}\Omega$

$R_3, R_4 = 510 \Omega$

$C_1 = 470 \mu\text{F}, 16 \text{ V}, \text{radial}$

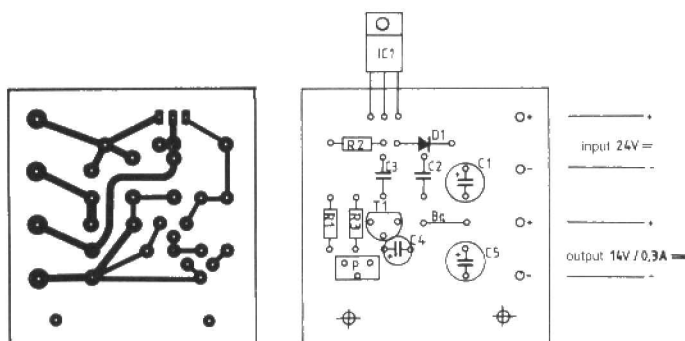
$C_2 = 0.68 \mu\text{F}, 63 \text{ V}$

$C_3 = 0.047 \mu\text{F}, 250 \text{ V}$

$C_4 = 10 \mu\text{F}, 35 \text{ V}, \text{tantalum}$

1 off PCC88

1 off noval socket for PCC88
for board mounting



Heater voltage board:

$R_1 = 2.2 \text{ k}\Omega$

$R_2 = 270 \Omega$

$R_3 = 150 \text{ k}\Omega$

$P = 1 \text{ k}\Omega$ preset potentiometer, radial

$C_1 = 47 \mu\text{F}, 35 \text{ V}, \text{radial}$

$C_2, C_3 = 0.1 \mu\text{F}, 100 \text{ V}$

$C_4 = 4.7 \mu\text{F}, 16 \text{ V}, \text{radial}$

$C_5 = 470 \mu\text{F}, 16 \text{ V}, \text{radial}$

$D_1 = 1\text{N}4148$

$T_1 = \text{BC}560$

$\text{IC}_1 = \text{LM}317$

calibration

Before the power is switched on, set P_1 and P_2 on the current amplifier board to the centre of their travel and the preset on the heater voltage board to minimum. Temporarily insert $10 \Omega, 1 \text{ W}$ resistors in the supply lines to the current amplifier board. The amplifier output should remain open.

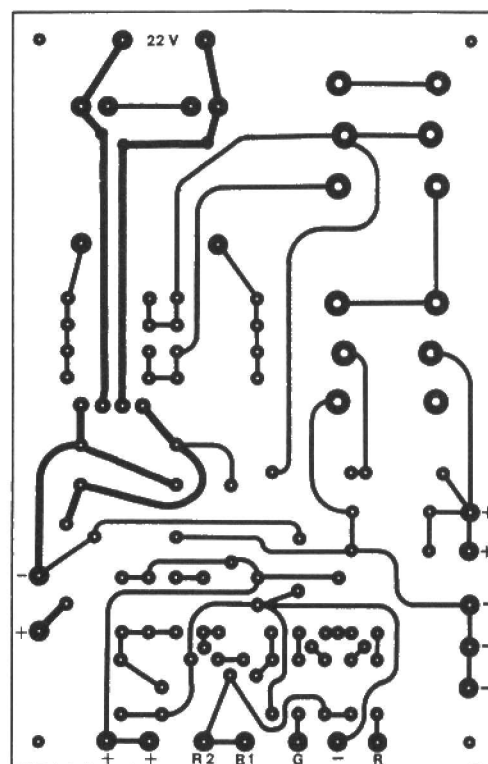
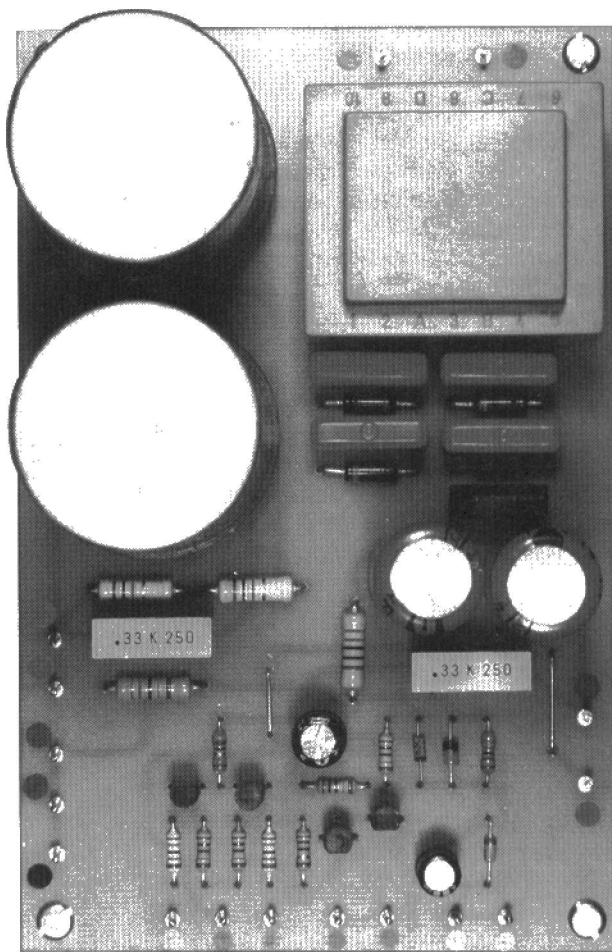
Switch on the mains and set the heater voltage to 14 V . Since the PCC88 is a series-regulated device, it

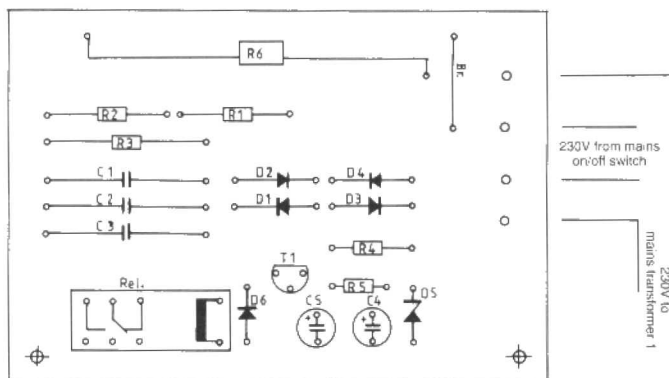
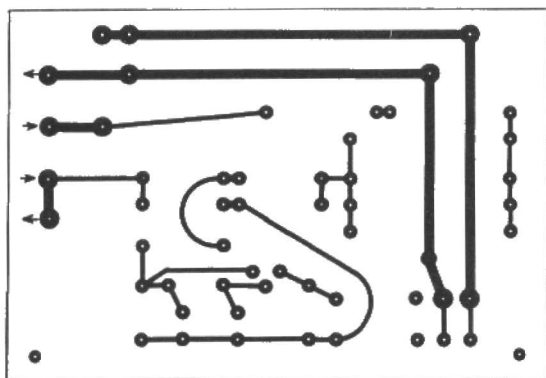
is, however, better, and more accurate, to set the heater current to 300 mA (after a heating up period of, say, 10 minutes).

Next, connect a digital voltmeter (DVM) across one of the 10Ω resistors and adjust P_1 to obtain a reading of 1 V , which corresponds to a quiescent current of 100 mA . Then, connect the DVM across the output terminals and adjust P_2 for a

reading of 0 mV .

Switch off the mains and remove the two 10Ω resistors. Switch on the mains again. Connect the DVM across R_{20} or





Soft-start board

$R_1, R_4 = 120 \Omega, 1 \text{ W}$

$R_2 = 150 \Omega, 1 \text{ W}$

$R_3 = 1 \text{ M}\Omega, 1 \text{ W}$

$R_5 = 10 \text{ k}\Omega$

$R_6 = 100 \Omega, 11 \text{ W}$

$C_1 = 0.1 \mu\text{F}, 250 \text{ V a.c.}$

$C_2, C_3 = 0.33 \mu\text{F}, 250 \text{ V}$

$C_4 = 470 \mu\text{F}, 16 \text{ V, radial}$

$C_5 = 100 \mu\text{F}, 16 \text{ V, radial}$

$D_1-D_4 = 1\text{N}4007$

$D_5 = \text{zener}, 15 \text{ V}, 1 \text{ W}$

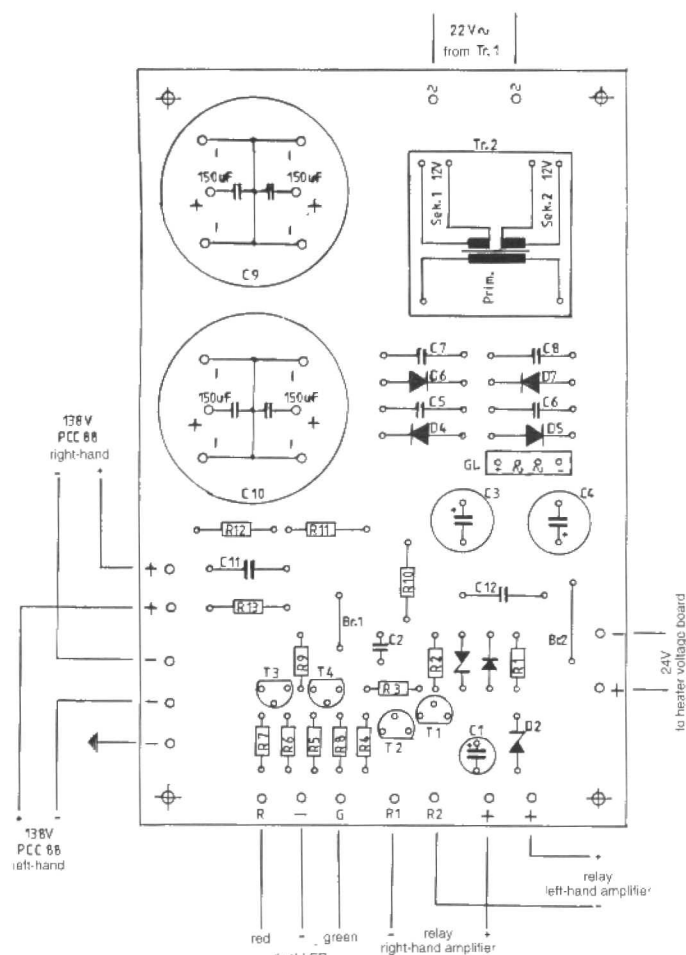
$D_6 = 1\text{N}4148$

$T_1 = \text{BC}550$

$\text{Rel}_1 = 12 \text{ V relay, 1 make contact, rating: } 16 \text{ A}$

R_{22} and adjust P_1 , if necessary, to obtain a reading of 230–250 mV. Leave the amplifier on for a couple of hours and recheck this voltage. Finally, connect the DVM across the output terminals and recheck that the reading is 0 mV, adjusting P_2 is necessary.

[97201]



Power supply board:

$R_1 = 330 \text{ k}\Omega$

$R_2, R_3, R_5, R_6 = 100 \text{ k}\Omega$

$R_4 = 10 \Omega$

$R_7, R_8 = 1.3 \text{ k}\Omega$

$R_9 = 100 \Omega$

$R_{10} = 220 \Omega, 1 \text{ W}$

$R_{11}, R_{12} = 1 \text{ k}\Omega, 1 \text{ W}$

$R_{13} = 220 \text{ k}\Omega, 1 \text{ W}$

$C_1 = 100 \mu\text{F}, 16 \text{ V, radial}$

$C_2 = 100 \mu\text{F}, 35 \text{ V, radial}$

$C_3, C_4 = 2200 \mu\text{F}, 40 \text{ V, radial}$

$C_5-C_8 = 0.01 \mu\text{F}, 250 \text{ V}$

$C_9, C_{10} = 150 \mu\text{F}, 350 \text{ V}$

$C_{11}, C_{12} = 0.33 \mu\text{F}, 250 \text{ V}$

$D_1 = 1\text{N}4148$

$D_2 = \text{zener}, 12 \text{ V}, 500 \text{ mW}$

$D_3 = \text{zener}, 10 \text{ V}, 500 \text{ mW}$

$D_4-D_7 = 1\text{N}4007$

$G_1 = \text{B}40\text{C}1500/1000$

$T_1, T_3 = \text{BC}550$

$T_2, T_4 = \text{BC}560$

$\text{Tr}_2 = 130 \text{ V primary, } 2 \times 12 \text{ V secondary transformer, rating: } 150 \text{ mA}$

Almost fifty years ago, *Wireless World* (now *Electronics World*) published the design of an audio output amplifier that gave a new dimension to hi-fi†. In the 1930s, Cossor Radio of London had introduced negative feedback (NFB) to improve the distortion characteristics of audio output amplifiers. After the Second World War, the beam tetrode, largely the work of the Marconi-Osram Valve Company of Wembley, London, offered a considerable improvement in distortion (without NFB) over the pentode while retaining the greater efficiency of this valve over that of the output triode. D. Williamson, an engineer working with Marconi-Osram, found that this advantage in efficiency was retained when the screen grid was connected to the anode to form a quasi-triode valve.

By B.v.d. Kerk

the Williamson amplifier revisited



legendary design of yesteryear

The function of an audio output amplifier is simply to convert a low-power input signal into a signal with sufficient

power to drive a loudspeaker and to do this with the least possible alteration of the input waveform. In the early days of audio engineering, this was accomplished by a two- or three-valve circuit

using a single output triode or pentode. By the 1930s, this had resulted in power amplifiers delivering up to 10 W audio power with a typical total harmonic distortion (THD) of 3–8 per cent.

† *Wireless World*, 55, 282, 1949

Manufacturers such as Cossor used negative feedback (NFB) to obtain improved stability, reduced distortion, and a more level frequency response. Williamson also used a substantial amount of overall NFB which, in conjunction with the interelectrode connection, resulted in audio power outputs of up to 15 W and a THD of 0.1 per cent, a truly remarkable improvement on the performance of amplifiers designed in the 1930s. Another important factor in the amplifier is the carefully designed output transformer to couple the relatively high output impedance of the amplifier to the low impedance of the loudspeaker.

circuit description

The circuit diagram of an amplifier based on the original Williamson design, excluding the power supply, is shown in **Figure 1**. The experienced reader will immediately distinguish three parts: the input stage with phase inverter, the driver, and the output stage. Since a good design is more than its constituent parts, it is usually left well alone. However, in the choice of valves and some other components, there is always some freedom of individual adaptation as long as the internal resistance, R_o , amplification factor, μ , and mutual conductance, g_m , of alternative valves are not too different from those of the original valves. Small differences may be compensated by suitable changes in the value of certain resistors.

The Williamson amplifier introduced

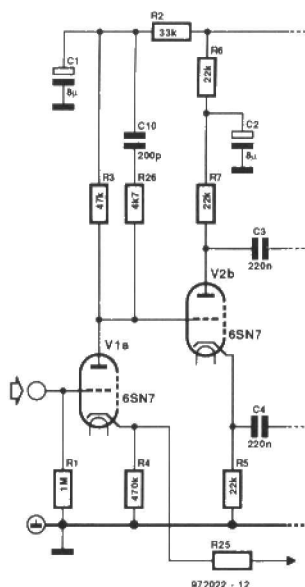


Figure 2. Input stage and phase inverter which originally used a Type 6J5 or 6SN7 valve.

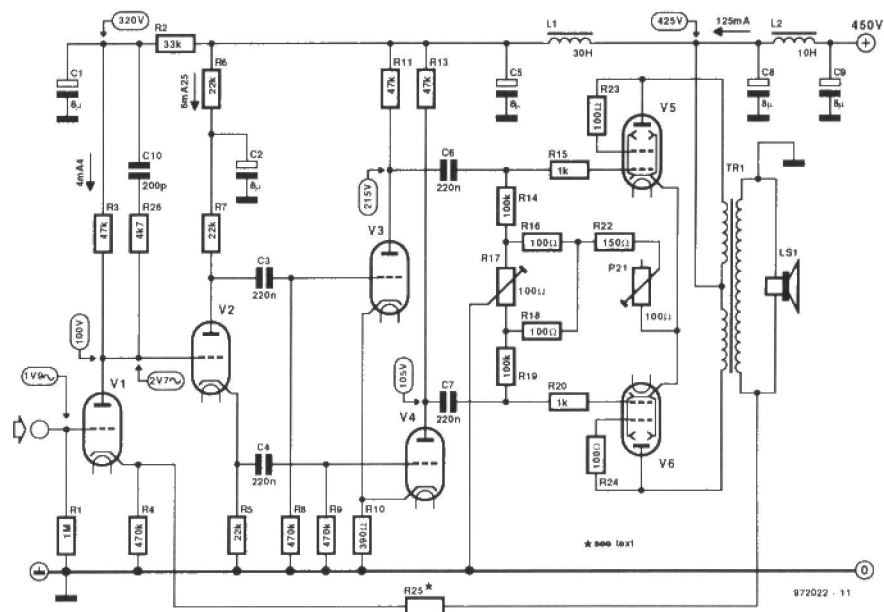


Figure 1. Circuit diagram of an original Williamson amplifier, excluding the power supply.

three novelties. First, direct coupling of the anode of the input stage to the grid of the phase inverter. Second, the layout of the basic circuit as a whole. Third, the design of the output transformer. In the 1940s, the output transformer was fairly large for the powers then handled, and it had a very wide frequency range.

input amplifier and phase inverter

Initially, Williamson used two Type 6J5 single triodes for the input amplifier and phase inverter, but later a Type 6SN7 double triode (see **Figure 2**), which is still available today. Nowadays, it is more convenient, however, to use a Type ECC82 (12AU7). The g_m of this valve is not as high as that of the earlier type, but this is easily compensated by giving the cathode resistor a slightly higher value to set the operating point of the stage. The anode potential is then about 100 V and, since the anode is coupled directly to the grid of the following stage, the cathode voltage of that stage becomes around 105 V and the anode voltage about 215 V. Because of the fairly low values of the cathode and anode resistors, not much can go wrong. Note, however, that the currents flowing in both stages are fairly large. We will revert to network R_{26} - C_{10} later.

The first stage has negative current feedback because of the non-decoupled cathode resistor. The distortion here will, therefore, be small. The open-loop gain is about $\times 10$. Note that in case of a stereo amplifier, the μ of the two stages must be equal. The phase

inverter does not amplify at all owing to the large amount of NFB by virtue of the unusually large cathode resistance.

driver stage

The same types of valve as in the input stages may be used for the driver (see **Figure 3**). Again, if an ECC82 is used, the value of the cathode resistor should be rather larger than specified in Figure 1. Frequently, a Type 12BH7 is used here with anode resistors smaller than specified (33 k Ω instead of 47 k Ω). The advantage of this is that it reduces the Miller effect of the output valves. This effect may be considered equal to a capacitor between the anode and grid of a valve. It is the most serious drawback in this design and largely determines the open-loop bandwidth

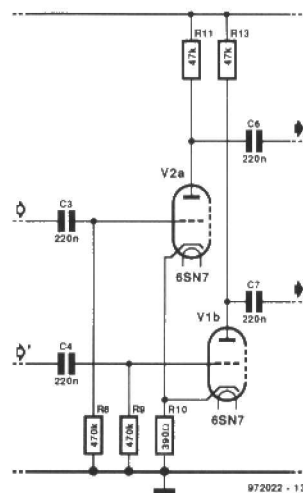


Figure 3. The driver stages use the same type of valves as the input stage.

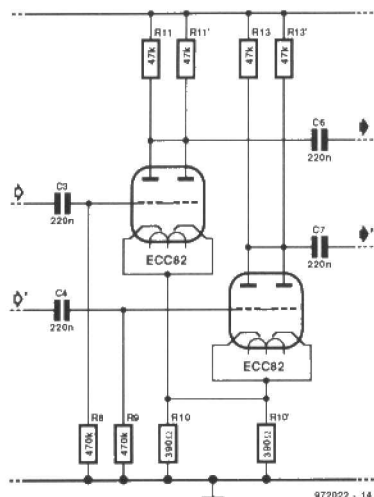


Figure 4. Alternative configuration of the driver stages using double triodes Type ECC82.

of the amplifier as a whole. The lower the value of the anode resistors of the driver stage, the faster the charge on the imaginary capacitance leaks away, and this makes the amplifier faster. When 12BH7 drivers and beam tetrode output valves are used, a bandwidth of 20 kHz is (just) possible (it is, of course, much larger when NFB is used).

It is also possible as shown in **Figure 4** to use two ECC82s in the driver stage and connect one half of each valve in parallel with one half of the other valve. The value of the cathode and anode resistors may then be halved.

When a 12BH7 is used, the value of

the common cathode resistor is chosen such that each half of the valve draws a current of about 4 mA. Note that the common cathode resistor does not provide NFB since, in spite of the small alternating voltages, the valves actively hold each other in almost perfect a.c. balance. This means that signals of equal phase are effectively suppressed and the valves get an improved I_a/V_g characteristic, which are considerable benefits. The amplification of the stage is about $\times 12$.

output stage

The output stage consists of a push-pull circuit of beam tetrodes arranged as triodes (screen grid strapped to anode). Triodes generate primarily even harmonics which in a push-pull circuit annul each other: an excellent property in a quality amplifier. Moreover, the R_a of a (quasi) triode is much smaller than that of a tetrode. The original Williamson amplifier used Type KT66 beam tetrodes (see **Figure 5**), but these are no longer easily available. Alternatives on the market are the Type 6L6/KT66 from Audio Note and the 6L6WGC/5881 from Sovtek, but these are not recommended because they cannot handle the dissipation in the long term. It is better to use a Type EL34 which, although it is a pentode, performs well in the circuit. In this case, the value of R_{22} should be changed to 100 Ω . The EL34 is fully driven by a 24 V r.m.s. signal, whereas a KT66 requires 38 V r.m.s.

As in the driver stage, the common cathode resistor is not decoupled. The amplifier operates in Class A throughout. This means that both valves are drawing current, however small, at all times. When the amplifier is overdriven, the current in one of the valves will become almost zero, while the other will experience a large amount of NFB via the cathode resistor, so that the gain cannot rise.

The dramatic effect of the common cathode resistor on the distortion can be seen in **Figure 6**. The characteristics refer to EL34 valves. Since this valve was developed as a replacement for the 6L6GC and similar types, it may be assumed that the characteristics of those valves are not very different. A secondary benefit of a non-decoupled cathode resistor is that the capacitor cannot be 'heard'.

With R_{17} set to the centre of its travel, adjust R_{21} to obtain an anode current (measured between the centre tap of the output transformer and the +ve supply line) of 125 mA. Next, set the

d.c. balance with R_{17} . If the resistances of the primary windings of the output transformer are equal (which is not always the case), adjust R_{17} so that the potential drops across the two windings are equal. In that case, the difference between the two direct voltages at the anodes is nil. If the resistances are not equal, Ohm's law will have to be applied.

Resistors R_{15} and R_{20} are stoppers to ensure that the output valves cannot go into oscillation. They should be soldered close to the valve socket. Resistors R_{23} and R_{24} serve to ensure that the maximum screen grid dissipation is not exceeded. If they are omitted, there is a strong possibility of the output valves going into oscillation. In case of the EL34, their value may be lowered to 47 Ω .

All resistors and potentiometers in the cathode circuit should be 4 W wire-wound types. Should the control grids of the valves become open-circuited, the valves will self-destruct within seconds.

negative feedback

Negative feedback for the overall amplifier is obtained via R_{25} between the secondary winding of the output transformer and the cathode of the input stage, V_1 . The value of this resistor depends on the output impedance and the desired degree of NFB. It is advisable to check with a large value, say, 150 k Ω , whether its insertion causes the gain to increase or decrease. If the gain increases, the feedback is positive, so that the connections to the secondary winding of the transformer must be interchanged. In the original Williamson amplifier, the NFB factor was 10 (that is, 20 dB). The factor is calculated by determining the reduction in amplification with NFB compared with that without. The smaller the value of R_{25} , the larger the amount of NFB, the lower the distortion, the larger the frequency range (but not the power bandwidth) and the larger the damping factor.

When the amplifier is used as a mono unit, it is beneficial to have a large damping factor, but in stereo applications the spatial aspects deteriorate with increasing feedback. With a feedback factor of 4, the distortion is acceptably low and the bandwidth sufficiently large. In most cases, however, the damping needed for the loudspeakers dictates the degree of feedback.

Some experimentation with the values of R_{25} and C_{10} is unavoidable. The

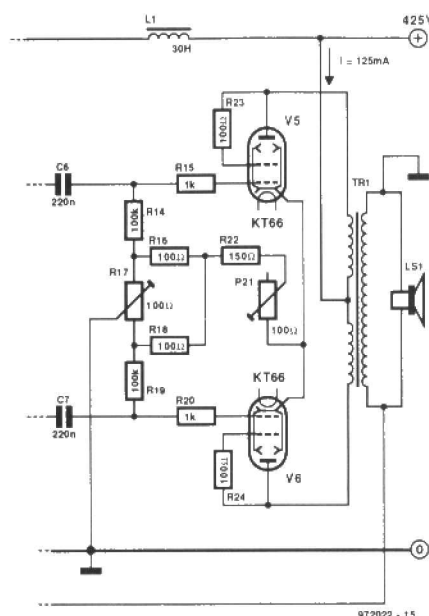


Figure 5. The output stage is a push-pull circuit using KT66 beam power tetrodes or EL34 pentodes.

value of the capacitor depends on the degree of feedback and on the properties of the output transformer. Normally, it will be between 100 pF and 200 pF, but to be precise it will have to be determined with the aid of an oscilloscope and a square-wave (function) generator after the requisite NFB has been fixed. Set the generator output to 10 kHz and observe the waveforms on the oscilloscope. Depending on the degree of NFB, the horizontal parts of the waveform will show some ringing (undulation). The larger C_{10} , the less ringing. Unfortunately, when the horizontal part of the waveform is flat, C_{10} has become too large: slight ringing gives the best performance. If the value of the capacitor has to be well in excess of 200 pF, a poor output transformer is indicated. The value of R_{26} may be retained as specified in virtually all cases.

At the same time, the oscilloscope will show the rise time of the amplifier, that is, how long it takes a leading edge to travel from base level to the onset of ringing: 5–6 μ s is excellent. If the amplifier is slower, it is best to increase the NFB slightly, but if it is faster, the sound is not any better. With some output transformers and a low NFB factor, network R_{26} - C_{10} may be omitted altogether.

output transformer

The output transformer in the original Williamson amplifier uses shell-type laminations equivalent to the current E-I 150 N format (150 mm high). The core has two identical chambers, each of which contains five primary windings. Each of these sections consists of four layers of 88 turns of 0.3 mm diameter enamelled copper wire. Each primary layer alternates with four secondary windings each consisting of two layers of 29 turns of 1 mm diameter enamelled copper wire. All layers are separated by 0.05 mm thick paper insulation. The windings are insulated by 0.4 mm thick oil-impregnated linen.

The primary sections are permanently connected in series aiding, and only three leads are brought out for the 10 k Ω anode-to-anode impedance and centre tap.

All secondary leads are brought out. To give the desired coupling, all secondaries are used at all times, from 1.7 Ω (all in parallel) to 109 Ω (all in series).

The essential characteristics are: primary inductance 100 H measured at 50 Hz, 5 V r.m.s.; primary resistance 250 Ω , leakage inductance 22 mH.

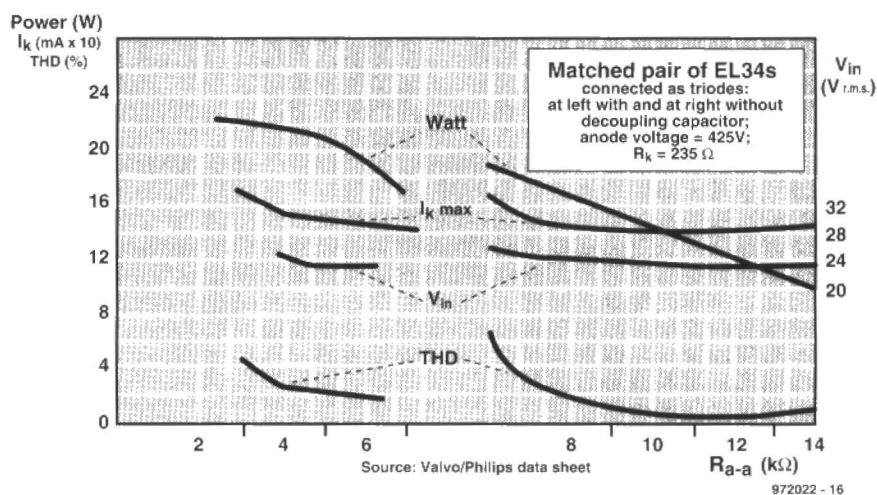


Figure 6. Total harmonic distortion characteristic when a push-pull output stage with EL34s is used.

According to the original specification, if the current flowing through the transformer is higher than 150 μ A, the transformer should be rejected! Clearly, it is virtually impossible nowadays to construct such a transformer. Nevertheless, if you want to try, bear in mind that the Williamson transformer used ordinary steel-plate laminations. With modern grain-oriented laminations a much smaller magnetizing force is required to produce the required flux, and this makes the requisite core smaller and the number of turns fewer.

The leakage inductance determines the high-frequency response. It is ascertained by short-circuiting the secondary and measuring the corresponding primary inductance at a frequency so low that the distributed capacitance is not effective, say, 50 Hz. The leakage inductance should not exceed 35 mH.

The most serious problem in finding a suitable alternative transformer is the primary impedance of 10 k Ω . It may be possible to use the 4 Ω output of a transformer with 5 k Ω primary imped-

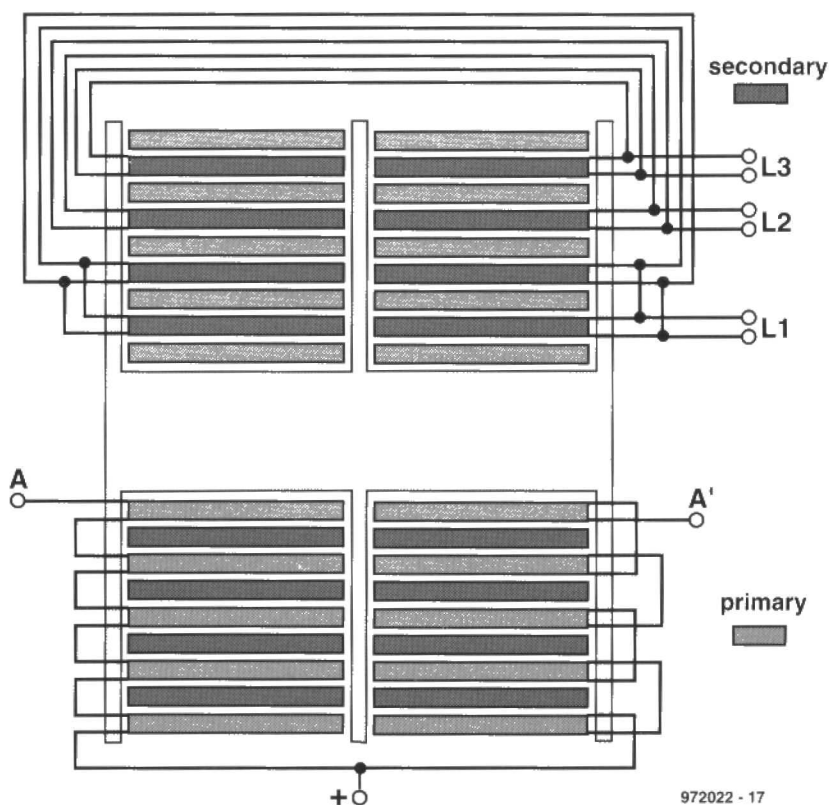


Figure 7. Basic construction of the Williamson output transformer.

ance (which is a lot easier to find) to drive 8 Ω loudspeakers.

The impedance ratio of an output transformer is the square of the turns ratio. This little knowledge may enable you to find a suitable transformer. Do not ignore the primary inductance or leakage inductance, however.

power supply

The original power supply used a valve rectifier Type 5V4, which requires a separate 5 V winding on the mains transformer. By today's standards, the electrolytic capacitors are small: only 8 μF . This is all right, however, since the amplifier operates in Class A which, owing to the evenly distributed load, does not make heavy demands on the power supply.

Chokes as used in the Williamson supply are a rarity nowadays. In the late 1940s, however, electrolytic capacitors were expensive and combinations of chokes and small electrolytic capacitors were much cheaper. Today, we would use a capacitor of, say, 1000 μF to get rid of any hum.

Choke L_1 may be replaced by a resistor across which a drop of about 10 V is acceptable. Of course, you may produce a choke by connecting all the windings of a small transformer in series and arranging the laminations so that all the Es are at one side and all the Is at the other. Bear in mind that chokes need to be well screened since they readily pick up hum from transformers. As mentioned earlier, it is much easier to use large value electrolytic capacitors rated at 550 V peak.

The high tension should not exceed 425 V at the centre tap of the output transformer, because the valves used do not tolerate higher voltages even if the current through them is reduced.

The EL34 requires a much higher heater current than the KT66. If hum on the heater leads (with alternating heater voltage) is troublesome, do not connect one of the heater leads to earth, but to a potential about 40 V above earth obtained with the aid of a voltage divider. Bear in mind that the heater current is of the order of 7 A.

To avoid damage to the electrolytic capacitors by peaks on the mains voltage, it is imperative that the high tension is not switched on until the valves have heated up. This may be effected by a separate switch or by an automatic power-on delay.

components

Coupling capacitors C_3 , C_4 , C_6 , and

C_7 should be polyester or polypropylene types rated at ≥ 630 V a.c.

Electrolytic capacitors C_1 , C_2 , C_5 , C_8 , and C_9 should have a working voltage of ≥ 450 V. Williamson specified a value of 8 μF for the first three, but larger is perfectly all right. If you don't use choke L_2 , the value of C_8 and C_9 in a stereo amplifier may be 400 μF or thereabouts.

The electrolytic capacitors are shunted by polypropylene types with a working voltage of 450 V for high-frequency decoupling.

Capacitor C_{10} should be a polyester type with a working voltage of 250 V d.c. A large, disused tuning capacitor may be handy to determine the requisite value of C_{10} as mentioned earlier.

All resistors, except those in the cathode circuit of the output valves, should be 1 W metal film types. Resistors R_5 and R_7 , and R_8 and R_9 should be selected on the basis of symmetry.

performance

The output power is about 15 W, which is more than enough for normal domestic use.

The THD is $<1\%$ without NFB and will decrease in proportion to the degree of NFB used.

Hum and noise cannot be discerned.

Without NFB, the input sensitivity is about 200 mV for maximum power output.

The amplifier is rock stable with open loudspeaker terminals and all kinds of load. It deserves to be used with high-quality loudspeakers.

finally

This article is not intended to be a detailed construction project of a valve amplifier, but rather as a stimulus to adapt the original Williamson circuit with modern parts and components. Unfortunately, the many aspects of such a project cannot be discussed within the framework of this short description. Do not rush into building the amplifier without first consulting a suitable book such as *Build your own valve amplifiers* (published by Elektor Electronics). Do take time to ponder over the project and to gather the necessary components, particularly the output transformer.

[972022]

Beginner's Guide to Tube Audio Design

By Bruce Rozenblit
ISBN: 1-882580-13-3
\$24.95

Now available from Audio Amateur Corp., *Beginner's Guide to Tube Audio Design* is the newest book from this pioneering publisher of DIY audio. Authored by Bruce Rozenblit, the book is a comprehensive discussion of tubes and audio design.

This complete beginner's guide on what vacuum tubes do and how to use them shows readers how to design with tubes. Rozenblit, a frequent contributor to AAC's *Glass Audio* magazine, starts with a clear explanation of what a vacuum tube is and how it works. The author steps through the basics of tubes, what their characteristics mean and how to read charts and specifications.

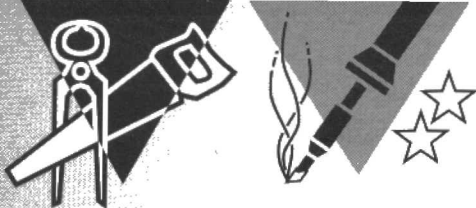
For more advanced readers, the author presents the complete picture of tube audio design, including single one-stage amplifiers, a simple gain circuit, negative feedback and how to use it, multistage basics and variations such as triode and ultralinear operation.

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Bruce Rozenblit is a graduate electrical engineer who owns and operates Transcendent Sound, a high-end amplifier manufacturing company. He has recently been awarded U.S. Patent No. 5,604,461 on a sophisticated new power amplifier.

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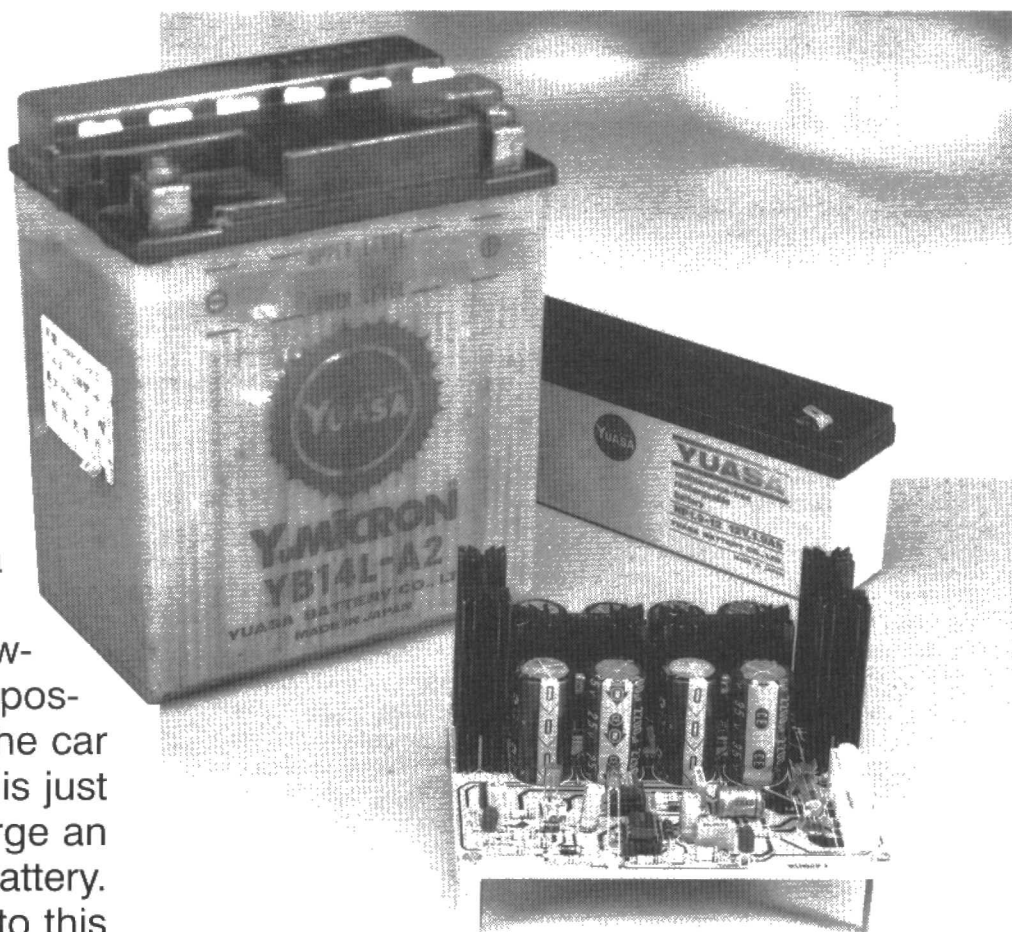


charging booster

extension for mobile battery chargers

Many model craft are powered by 12 V rechargeable batteries. Often, it would be a godsend if these batteries could be charged by a lead-acid (12 V) car battery. However, that is not possible, since the car battery voltage is just sufficient to charge an eight-cell (9 V) battery.

One solution to this problem is, therefore, to raise the car battery voltage and this is what the booster presented in this article does. In conjunction with the car battery, it enables 12 series-connected cells to be charged at charging currents of up to 4 amperes.



INTRODUCTION

In contrast to the ease with which alternating voltages can be raised, it is fairly cumbersome to increase the level of a direct voltage. It can be done, of course, and there are, indeed, several ways of so doing. One is an integrated step-up converter with high tension cascade, another is a charge pump (also called super voltage converter). Whatever means is used, it is always necessary to convert the direct voltage into an alternating one. Only then can the level be raised.

In the present booster, the main part of the circuit is the charge pump shown in **Figure 1**. The pump, which has two modes of operation, consists of two diodes, two capacitors and a change-over switch. The

switch alternately links a terminal of one of the capacitors to the supply rail and to earth.

Charging (Figure 1a)

When the pump is in the charging mode, that is, when the switch is linked to earth, the capacitors are virtually in parallel, separated only by D_B . Capacitor C_A is charged to nearly the level of the supply voltage via diode D_A . At the same time, capacitor C_B retains the charge it already had. Since the potential across this capacitor during normal use is higher than that across C_A , diode D_B is reverse-biased. Capacitor C_B is fully charged only at switch-on and is then charged, together with C_A , to the level of the supply line via D_B .

Design by J. Dietrich

Pumping (Figure 1b)

In the pumping mode, the terminal of C_A that was linked to earth is connected to the positive supply rail via the switch. Its charge is then transferred to C_B , so that the potential across this capacitor is (nearly) doubled.

SWITCHING AND CONTROL

The practical design of the setup in Figure 1 is shown in Figure 2. The supply voltage is derived from the car battery via K_1 . The change-over switch consists of two power MOSFETs, T_4 and T_5 . Transistor T_4 serves to link parallel connected capacitors C_7 – C_{10} (equivalent to capacitor C_A in Figure 1) to the supply line, while transistor T_5 provides the link to earth. Capacitors C_{11} – C_{14} are equivalent to C_B in Figure 1.

Unfortunately, a practical charge pump suffers from some amount of loss. In this case, these losses are caused by the drops across the diodes, the (limited) capacitance of the electrolytic capacitors, and the on-resistance of the MOSFETs. Owing to these losses, the output level of the pump is not twice the car battery voltage, but about 1.85 times under no-load conditions and around 1.5 times when a current of 4 A is drawn by the load. This means that the efficiency varies from 91% under no load conditions to

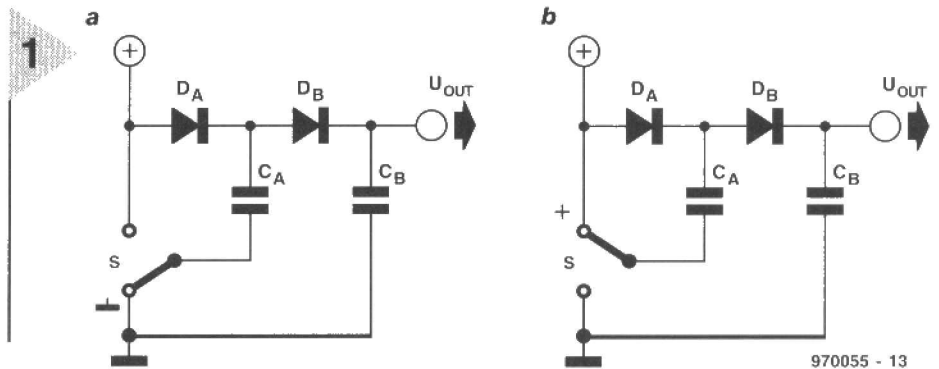


Figure 1. Principle of the charge pump: when the potential across C_A is inverted, the charge of this capacitor is superimposed on to that of C_B .

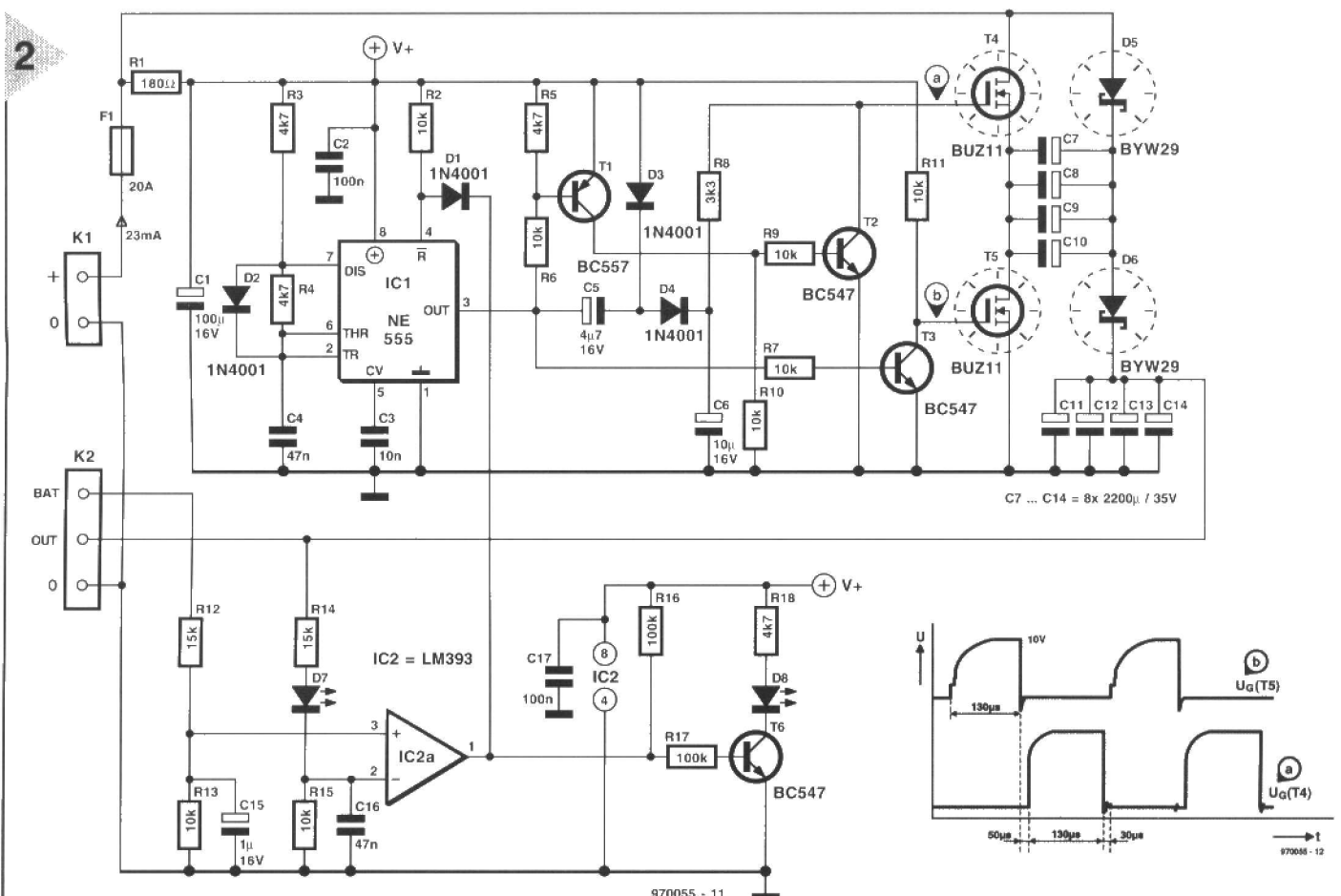
75% at maximum load.

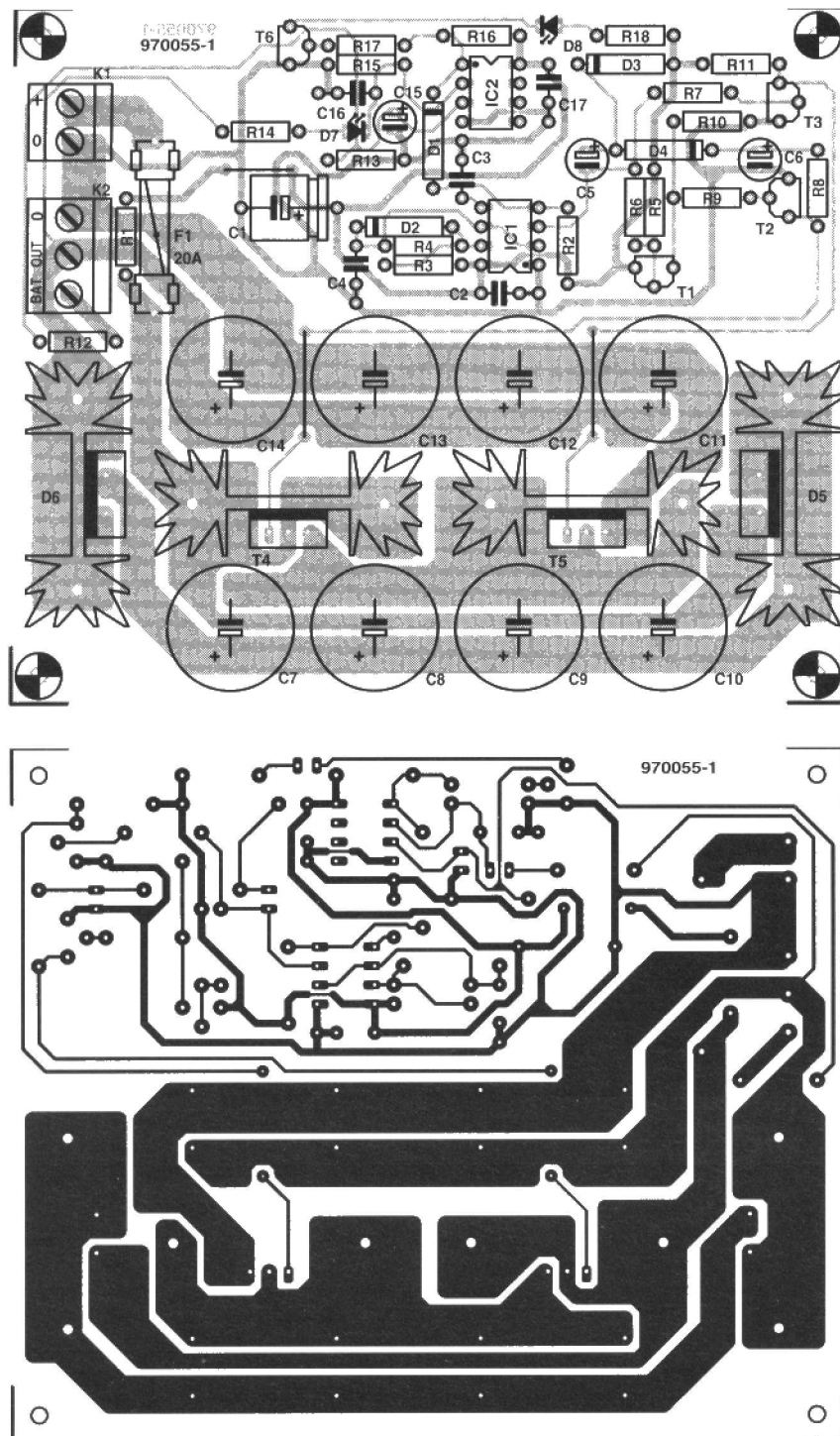
The switching transistors are controlled by a timer, IC_1 , which is configured as a rectangular-wave generator. The generator frequency is determined by R_3 , R_4 and C_4 ; with values of these components as specified, it is about 3 kHz. Diode D_2 ensures that the on and off periods are about equal to give a duty factor of around 0.5. It should be borne in mind, however, that the switching times of transistors play a significant role. Those of the BUZ11 used in the booster amount to a few microseconds. To prevent both transistors briefly conducting simultaneously, which would result in large short-circuit currents, a dead period has been provided around the switch-over times.

Optimum control of the transistors is provided by a network consisting of

R_7 , R_8 , C_5 , C_6 , D_3 and D_4 . The figure inset into Figure 2 shows the voltage variations at the gates of the MOSFETs. It will be seen that the transistors are controlled by 130 μ s wide pulses. Each

Figure 2. The circuit of the booster consists of a charge pump, a rectangular-wave generator and voltage regulator.





Parts list

Resistors:

$R_1 = 180 \Omega$
 $R_2, R_6, R_7, R_9-R_{11}, R_{13}, R_{15} = 10 \text{ k}\Omega$
 $R_3-R_5, R_{18} = 4.7 \text{ k}\Omega$
 $R_8 = 3.3 \text{ k}\Omega$
 $R_{12}, R_{14} = 15 \text{ k}\Omega$
 $R_{16}, R_{17} = 100 \text{ k}\Omega$

Capacitors:

$C_1 = 100 \mu\text{F}, 16 \text{ V}$
 $C_2, C_{17} = 0.1 \mu\text{F}$
 $C_3 = 0.01 \mu\text{F}$
 $C_4, C_{16} = 0.047 \mu\text{F}$
 $C_5 = 4.7 \mu\text{F}, 16 \text{ V}, \text{radial}$
 $C_6 = 10 \mu\text{F}, 16 \text{ V}, \text{radial}$
 $C_7-C_{14} = 2200 \mu\text{F}, 35 \text{ V}, \text{radial}$
 $C_{15} = 1 \mu\text{F}, 16 \text{ V}, \text{radial}$

Semiconductors:

$D_1-D_4 = 1\text{N}4001$
 $D_5, D_6 = \text{BYW}29$
 $D_7 = \text{LED, yellow, high efficiency}$
 $D_8 = \text{LED, red, high efficiency}$
 $T_1 = \text{BC}557$
 $T_2, T_3, T_6 = \text{BC}547$
 $T_4, T_5 = \text{BUZ}11$

Integrated circuits:

$\text{IC}_1 = \text{NE}555\text{N}$
 $\text{IC}_2 = \text{LM}393\text{P}$

Miscellaneous:

$F_1 = \text{fuse, } 20 \text{ A, slow, complete with holder for board mounting}$
 $K_1 = 2\text{-way terminal block, pitch } 5 \text{ mm}$
 $K_2 = 3\text{-way terminal block, pitch } 5 \text{ mm}$
 $\text{HS}_1, \text{HS}_2 = \text{heat sink, Fischer SK104/50.8 mm (9 K W}^{-1}\text{)}$
 $\text{HS}_3, \text{HS}_4 = \text{heat sink, Fischer SK104/38.1 mm (11 K W}^{-1}\text{)}$

Figure 3. Printed-circuit board for the charging booster.

pulse is followed by an interval of $30\text{--}50 \mu\text{s}$, provided by network $R_6\text{--}R_8\text{--}C_5\text{--}C_6$, during which neither of the gates is driven. Only when the interval (i.e., dead period) has elapsed, does a pulse arrive to drive one of the transistors into conduction.

Comparator IC_{2a} is here used as voltage regulator. It likens the terminal voltage of the battery to be charged (connected to BAT on K_2) with the output (OUT on K_2). The comparator changes state (i.e., its output goes low) when $U_{\text{OUT}} > U_{\text{BAT}} + U_{D7}$. The $\overline{\text{R}}(\text{reset})$ input of IC_1 then goes low, which results in the oscillator being disabled. The charge pump is reactivated only

when the potential across $C_{11}\text{--}C_{14}$ is less than 1.75 V (the threshold voltage of the LED) higher than the nominal voltage of the model craft battery. This ensures that the regulator has sufficient reserve in its operating range.

CONSTRUCTION

The booster is best built on the printed-circuit board shown in Figure 3 (which is, however, not available ready-made). Owing to the large electrolytic capacitors and the requisite heat sinks, the booster is not small, but is, nevertheless, easy to build. Provided that the wire bridges adjacent to C_2 , between C_{13} and C_{14} and between C_{11} and C_{12} are not over-

looked, nothing much can go wrong.

The power transistors and diodes need suitable heat sinks: those for the diodes are slightly larger at 9 K W^{-1} than those for the transistors at 11 K W^{-1} . None of these components needs to be isolated from the relevant heat sink, but they should be provided with a good layer of heat conducting paste before they are screwed together. Note that in order to obtain a robust construction, the fixing pins of the heat sinks must be soldered on to the board.

The remainder of the circuit is fitted on the other half of the board – see Figure 4.

The yellow LED is used as a volt-

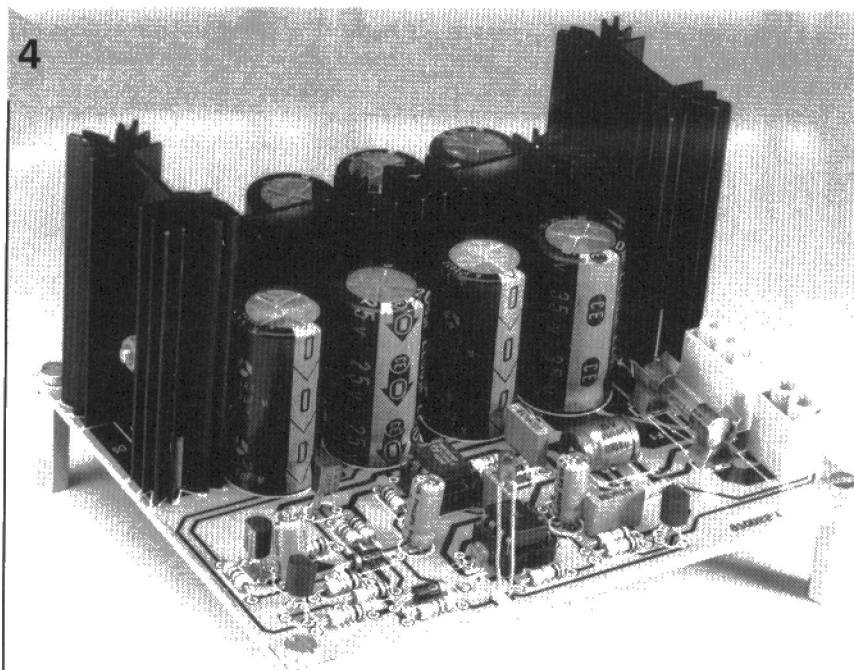


Figure 4. Photograph of the completed prototype without housing. Notice the difference in size of the heat sinks for the diodes and those for the power transistors.

age reference, and the red one indicates whether the booster is operating from a high enough voltage.

The 20 A fuse is a final protection for the power transistors should a short-circuit occur.

FINALLY

The booster must be inserted between the car battery and that of the model craft.

Connect the car battery leads to K₁ and link the supply lines of the charger to K₂ (OUT and 0).

Link the BAT terminal of K₂ to the +ve terminal of the model craft battery.

It is recommended to house the booster in a robust polythene case. The red LED should then be located on the front panel. If there is no need for a visual indication, this diode may be omitted.

[970055]

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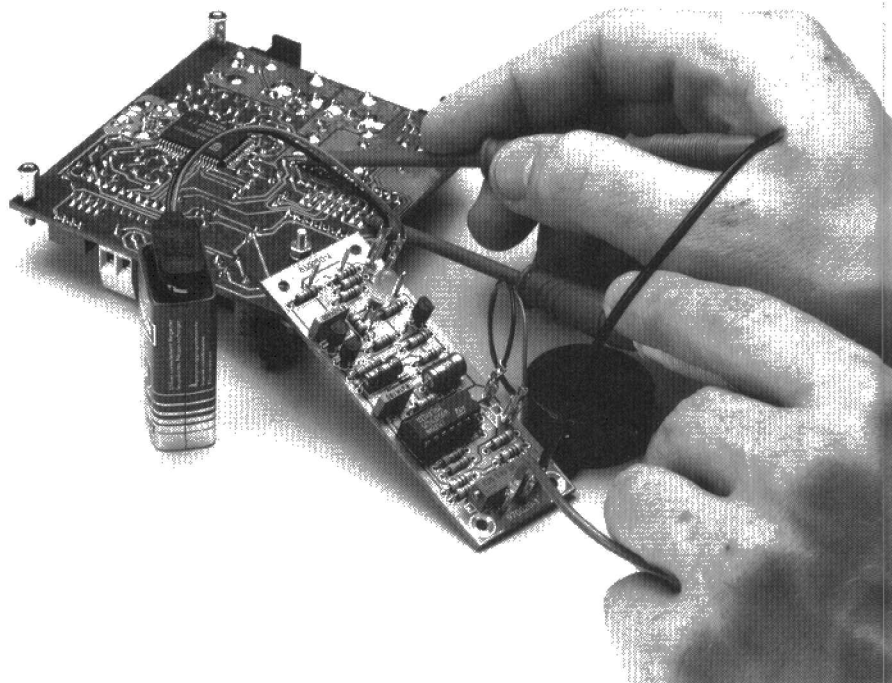
STE



dual continuity tester

for low- and high-impedance links

The article describes an instrument that is likely to become a standard unit in the toolbox of many electronics technicians. It functions not only as a standard acoustic continuity tester but also as a kind of wireless speedtester with which it suffices to merely touch the device to be tested with a finger. Its user-friendliness is further enhanced by its knob-less switch-on system and an economizing automatic switch-off system.



INTRODUCTION

The tester consists of a combination of two circuits that strictly speaking could be separated from one another. It is, however, the fact that they are combined that makes the tester such a useful unit.

There is nothing special about the part of the circuit that functions as the low-impedance continuity tester. It is a fairly standard test circuit that is useful in tracing bad connections, breaks in PCB tracks, unreliable connectors, and wiring errors. However, in this application, light-bulbs, relay solenoids, and diodes, are not considered 'true' connections. This is because the tester responds only to paths that have a resistance $< 5\text{--}15\ \Omega$. The exact level can be set with a potentiometer. It

should be noted that the test voltage is low, so there is no risk of damaging sensitive components or parts. Findings are made audible by a piezo buzzer.

The speedtester is rather different. It, too, is a continuity tester, but is intended for the rapid checking of, say, a motor winding or a light-bulb. A special aspect of it is that testing can be carried out without the use of leads: owing to its high-impedance character, the test may be made by hand. One test pin of the speedtester may consist of a screw or metal lip against which one of the terminals of, say, the light-bulb is pressed. The other test pin is a metal strip or something like it that is touched automatically when the tester is held in the hand. If then the other

terminal of the light-bulb is touched with the hand not holding the tester, the high-impedance loop is closed (if the bulb is all right) and this is indicated by an LED. If this diode does not light, the bulb is faulty.

The tester is powered by a standard 9-V alkaline battery. The speedtester only draws current when the LED lights and this makes an on/off switch superfluous. The low-impedance continuity tester is switched with the aid of an additional terminal. If this terminal is touched by one of the test pins, it does not matter which, the circuit is switched on for about 3 minutes. After this period has elapsed, the tester is automatically

human skin lies between a few hundred kilohms and a few megohms. So, just shorting the two inputs pins by finger will result in T_1 conducting and switching on T_2 , whereupon D_2 (green) lights.

The remainder of the circuit is the standard low-impedance tester with automatic on/off switching. The test leads are connected to pins PC_1 and PC_2 . When PC_5 is touched by one of the test leads, the collector-emitter junction of T_4 is shorted briefly by R_{17} (possibly in conjunction with R_{15}). This will cause T_3 to conduct so that the battery is connected to the circuit. Since the potential at the non-inverting input of IC_{1d} is more positive than that across (discharged) capacitor C_2 ,

across R_{10} , whereupon the output of IC_{1d} goes low. Transistors T_3 and T_4 gradually stop conducting; this process is accelerated by the potential across R_{10} dropping, which makes the output of IC_{1d} go even lower. This process causes the supply to the tester to be switched off fairly abruptly after about three minutes.

CONSTRUCTION

The printed-circuit board shown in Figure 2 makes building the tester pretty straightforward. If nevertheless it does not work upon completion, inspect it carefully for any errors. If none is found, verify that the voltages on the board correspond with those given in the circuit diagram. Note that

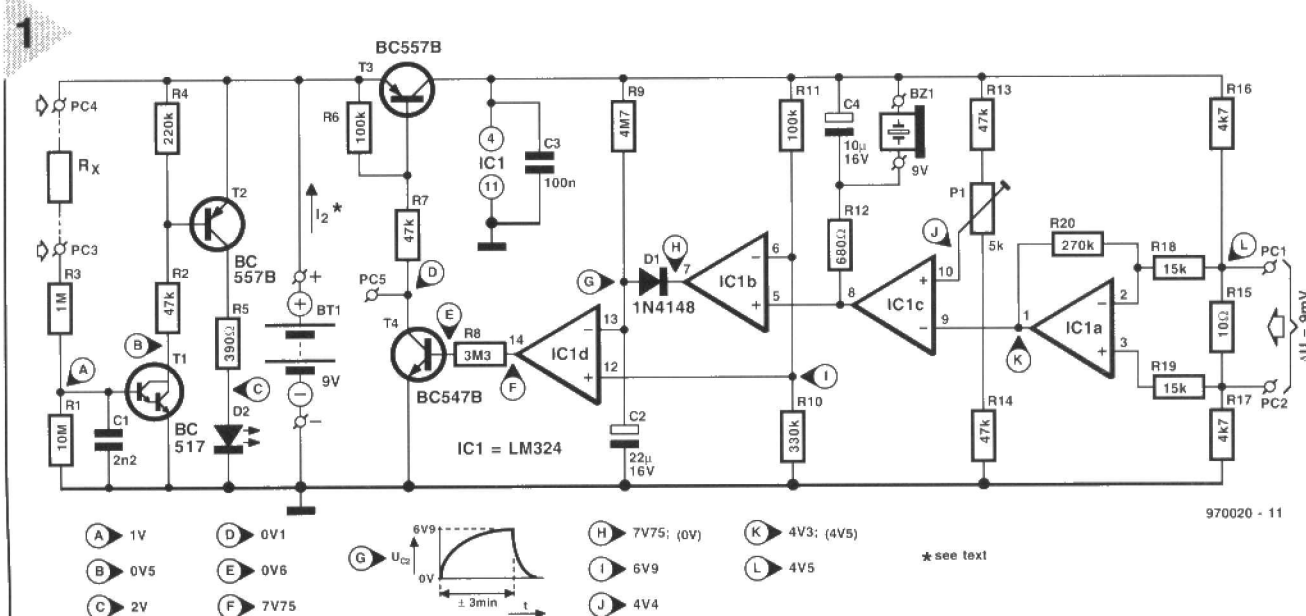


Figure 1. The unit described consists of two testers: a speedtester (to the left of the battery) and a standard low-impedance one with automatic on/off switching.

switched off again. The 3-minute period is lengthened by three minutes every time the buzzer sounds. In practical operation, this arrangement has proved to be very convenient and economical.

CIRCUIT DESCRIPTION

The circuit diagram of the dual tester is given in Figure 1: it shows quite clearly that the design consists of two distinct parts.

The circuit to the left of battery BT_1 is that of the speedtester. In essence, it is no more than a very sensitive direct-current amplifier consisting of a darlington transistor, T_1 , and a common-or-garden transistor, T_2 , which drives light-emitting diode D_2 .

Because of the very high gain of T_1 , this transistor needs only a tiny base current to switch on: a fairly-high-impedance between input pins PC_3 and PC_4 is sufficient. The resistance of

the output of the op amp is positive. This means that T_4 is switched on and maintains the base current of T_3 .

The continuity tester proper is formed by comparators IC_{1a} and IC_{1c} . The inputs of these stages are linked to resistance bridge P_1 - R_{13} - R_{17} . This bridge is adjusted with P_1 to make the non-inverting input of IC_{1c} slightly more positive than the inverting input. When R_{15} is shunted by a low-value resistance, the output of IC_{1a} , and therefore the input of IC_{1c} , becomes more positive. The output of IC_{1c} then goes low and this causes buzzer BZ_1 to sound.

When the level at the output of IC_{1c} has dropped below 75% of the supply voltage, the output of IC_{1b} goes low, whereupon C_2 is discharged rapidly via D_1 . When the output of IC_{1b} becomes high again, C_2 is recharged very slowly via R_9 . After about three minutes, the potential across the capacitor is equal to that

in the case of the speedtester these voltages apply only when D_2 lights, and in the case of the low-impedance tester when the buzzer is actuated.

Selecting a suitable case should, in view of the compactness of the tester, prove not too difficult.

It may be convenient to link PC_1 and PC_2 to simple PCB mounting sockets for use with bananaplug terminated test leads. Test pin PC_5 may consist simply of a small screw fitted adjacent to these sockets.

In the speedtester, PC_4 may be linked to an M3 screw protruding slightly from the case, while PC_3 may be linked to a small piece of alu-

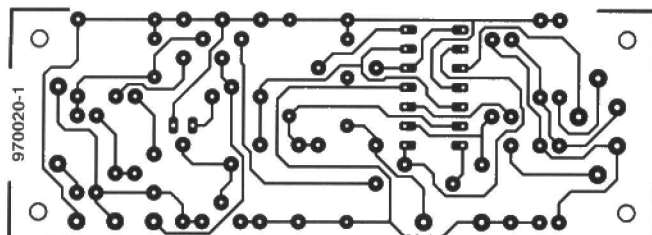
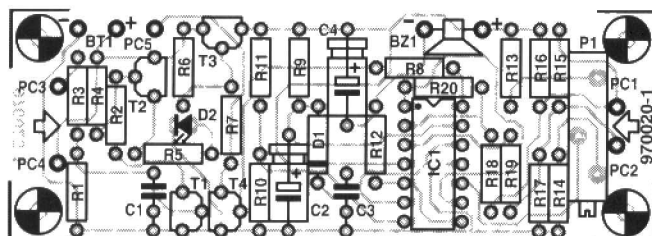


Figure 2. Printed-circuit board for the tester. It ensures easy and straightforward completion of the tester. All connections are marked clearly.

Parts list

Resistors:

$R_1 = 10 \text{ M}\Omega$
 $R_2, R_7, R_{13}, R_{14} = 47 \text{ k}\Omega$
 $R_3 = 1 \text{ M}\Omega$
 $R_4 = 220 \text{ k}\Omega$
 $R_5 = 390 \Omega$
 $R_6, R_{11} = 100 \text{ k}\Omega$
 $R_8 = 3.3 \text{ M}\Omega$
 $R_9 = 4.7 \text{ M}\Omega$
 $R_{10} = 330 \text{ k}\Omega$
 $R_{12} = 680 \Omega$
 $R_{15} = 10 \Omega$
 $R_{16}, R_{17} = 4.7 \text{ k}\Omega$
 $R_{18}, R_{19} = 15 \text{ k}\Omega$
 $R_{20} = 270 \text{ k}\Omega$
 $P_1 = 5 \text{ k}\Omega, 10\text{-turn, preset}$

Capacitors:

$C_1 = 2.2 \text{ nF}$
 $C_2 = 22 \mu\text{F}, 16 \text{ V}$
 $C_3 = 100 \text{ nF}$
 $C_4 = 10 \mu\text{F}, 16 \text{ V}$

Semiconductors:

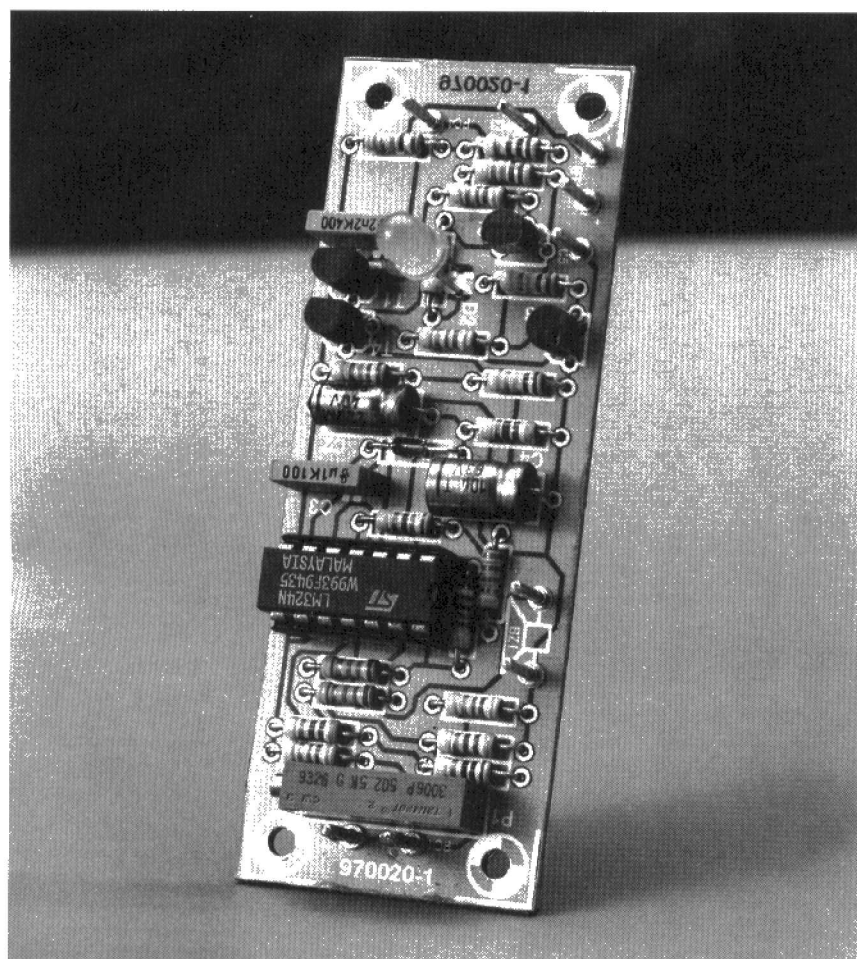
$D_1 = 1\text{N}4148$
 $D_2 = \text{LED, green}$
 $T_1 = \text{BC}517$
 $T_2, T_3 = \text{BC}557\text{B}$
 $T_4 = \text{BC}547\text{B}$

Integrated circuits:

$\text{IC}_1 = \text{LM}324$

Miscellaneous:

$\text{Bt}_1 = 9\text{-V alkaline battery}$
 $\text{Bz}_1 = 9\text{-V piezo-electric d.c. buzzer}$
 9 off board terminals
 PCB Order no. 970020



minium on the outside of the case. This should be fitted in a position where it is always automatically touched when the case is held in the hand.

The tester is calibrated by simply short-circuiting the test leads and adjusting P_1 until buzzer Bz_1 just begins to sound. If the connections to be tested have an impedance $>15 \Omega$, they fall outside the range covered by P_1 .

The speedtester draws a current of about 20 mA when D_2 lights. Although

this appears rather high, bear in mind that most tests are very short, so that the overall drain remains low.

If a higher battery life is desired, use of a high-efficiency LED should be considered. If this change is effected, the value of R_5 must be $\times 10$ greater.

The low-impedance tester draws a current of about 3.6 mA when the buzzer sounds and 2.0 mA otherwise.

Even when the tester is used regularly, a 9-V battery should last about a year.

[970020]

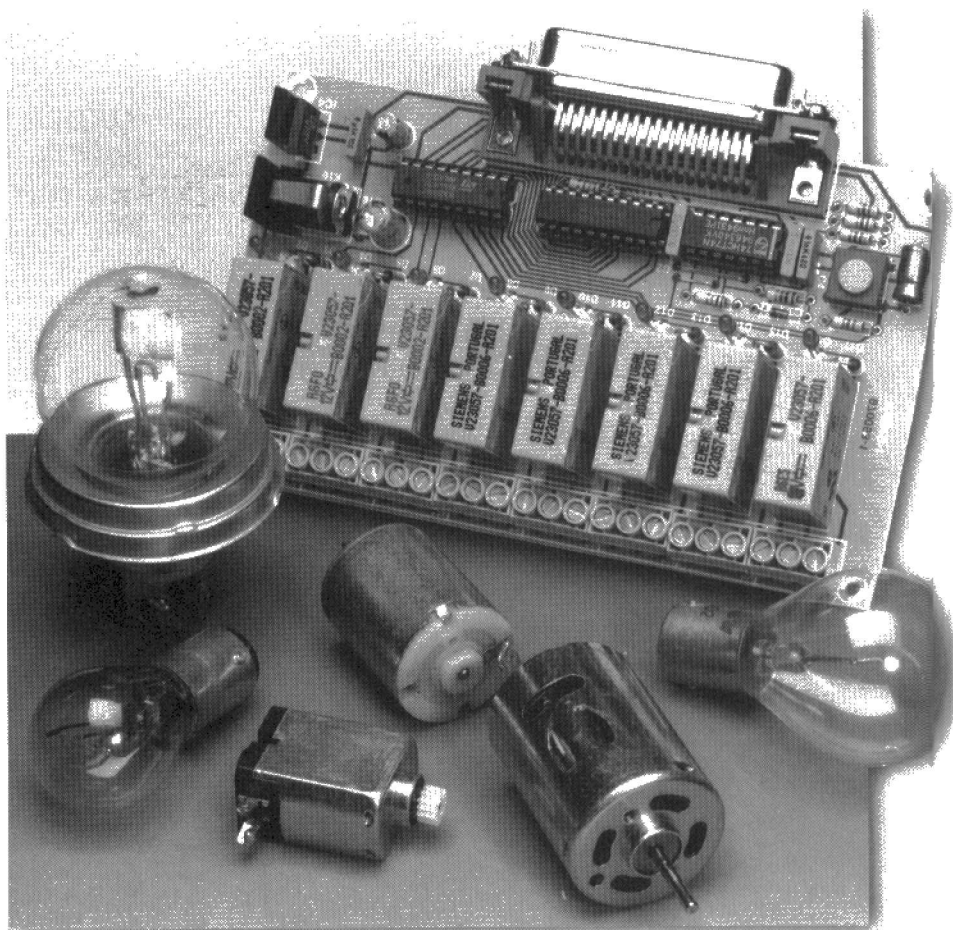


Centronics relay card

do more with the PC printer port

A relay is still one of the simplest devices for switching large electrical loads with the aid of a relatively small amount of energy. Since a computer is perfectly suitable when it comes to generating switching commands according to a certain pattern, the combination of a PC and a number of relays results in a multi-purpose, flexible, switching system. The relay card presented in this article is the safe link between the PC's parallel port and other equipment. The fact that the port may be controlled with very simple commands allows you to experiment with the circuit to your heart's content.

Design by K. Walraven



A compact circuit board, accommodating no fewer than eight relays which can be switched as you desire, using simple print commands; that's basically what this project has in store. The relays used are types with a changeover contact, so that normally closed (n.c) or normally open (n.o) contacts may be implemented, depending on the connections you make. Because all components are fitted on a single board, with the exception of the mains adaptor, a compact circuit is obtained, while the risk of construction errors is minimized. The software side of things has been kept very simple, too: in fact, you only use the LPRINT statement in BASIC.

Installing and connecting the card is also a piece of cake: hook it up to the printer port and Bob's your uncle.

This relay card is without doubt a project which enables anyone to turn his/her computer into a versatile switching unit. Its application, by the way, need not be restricted to an MS-DOS PC; any computer having a parallel printer port should be able to control the circuit.

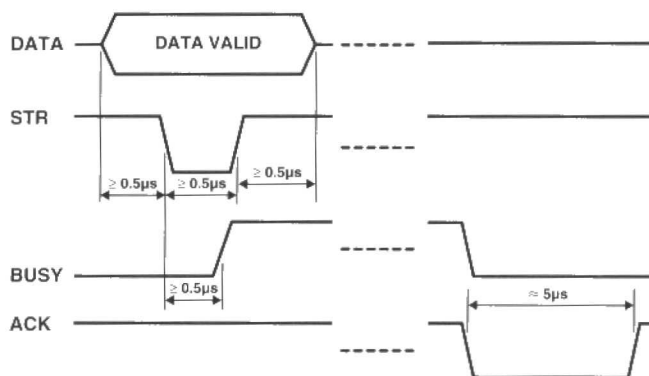
HOW IT'S DONE

The protocol used by the Centronics (or 'parallel printer') port is really quite simple. The port consists of an 8-bit databus and three control lines. In most cases, only two of the three con-

trol lines are used. The computer employs the strobe signal to indicate that the data on the databus are stable and valid, while the peripheral device (a printer or, in this case, a relay card), uses the busy and/or acknowledge line to inform the computer that a command has been received and executed. A rundown of the communication process is shown in **Figure 1**. Because the computer may process either the busy or acknowledge signal, both options are catered for by the relay card. In other words, it generates a busy as well as an acknowledge signal.

Although the Centronics bus comprises a number of so-called status lines, these are not used here. For the present application, only the part that arranges the data traffic is essential. This traffic complies with the following protocol: the PC puts the dataword on the 8-bit wide bus (pins 2-9), and then waits (min. $0.5\mu\text{s}$). Next, it pulls the strobe line (pin 1) logic low. After another small delay of at least $0.5\mu\text{s}$ it returns the strobe line to logic high. This causes the peripheral (i.e. our relay card) to copy the dataword. The PC should leave the dataword unchanged for at least $0.5\mu\text{s}$.

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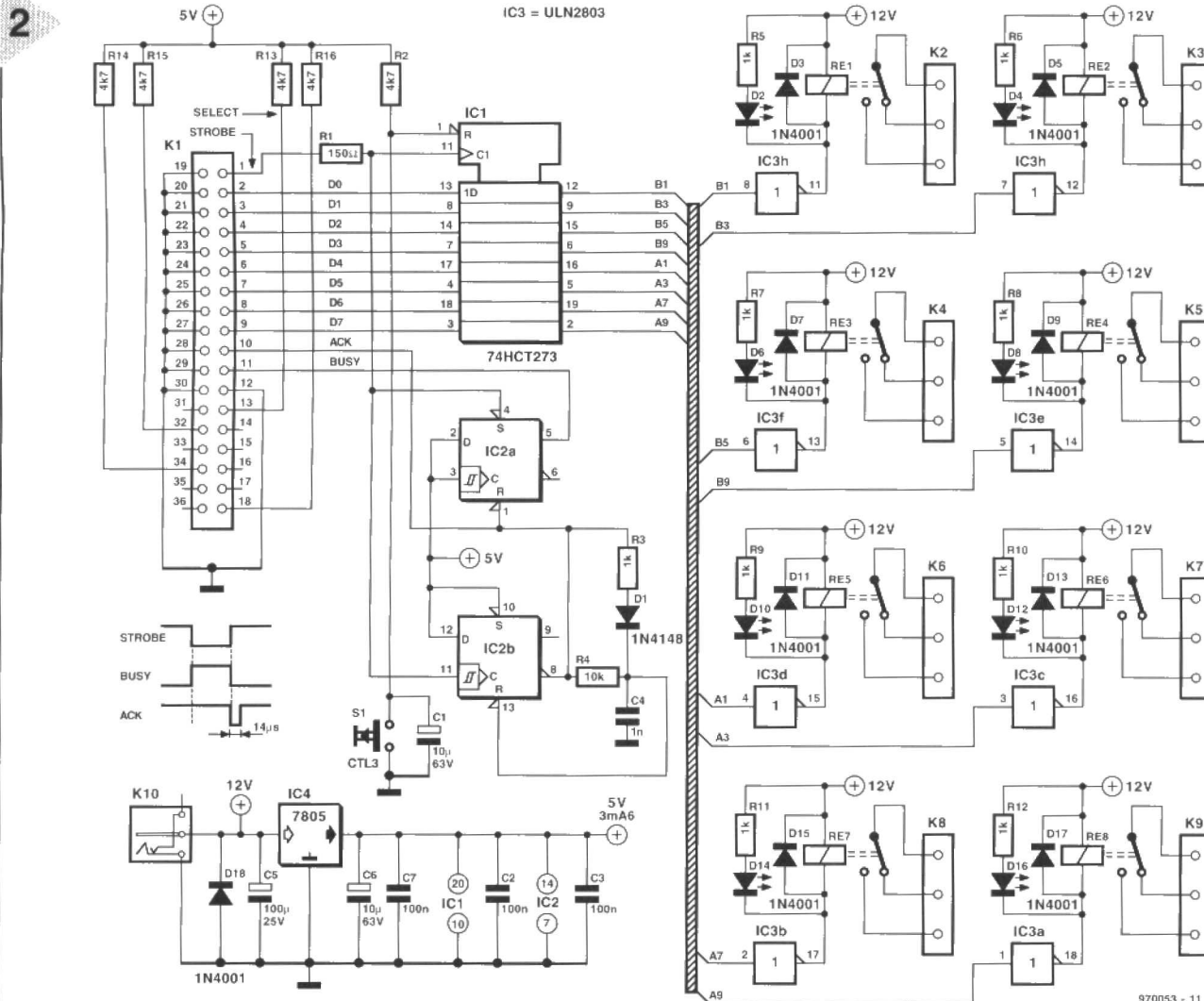
Figure 1. Communication process between computer and printer when data is conveyed via the parallel port.

Returning to the actual hardware, the circuit diagram of the circuit is shown in **Figure 2**. Apart from the power supply, the entire circuit consists of just three elementary integrated circuits. The eight databits (D0-D7 on the printer port) are latched by IC1, a type 74HCT273. Pin 11 of this IC receives the strobe signal supplied by

the printer port, while the CLR input (pin 1) is controlled by an internally generated reset signal furnished by R2 and C1. The rising edge which marks the end of the strobe pulse causes the latch to transfer the information at the D inputs to the associated Q outputs.

A dual bistable type 74HCT74 is used to generate the control signals, busy and acknowledge. IC2b is wired as a monostable multivibrator (MMV).

Figure 2. Circuit diagram of the Centronics relay card.



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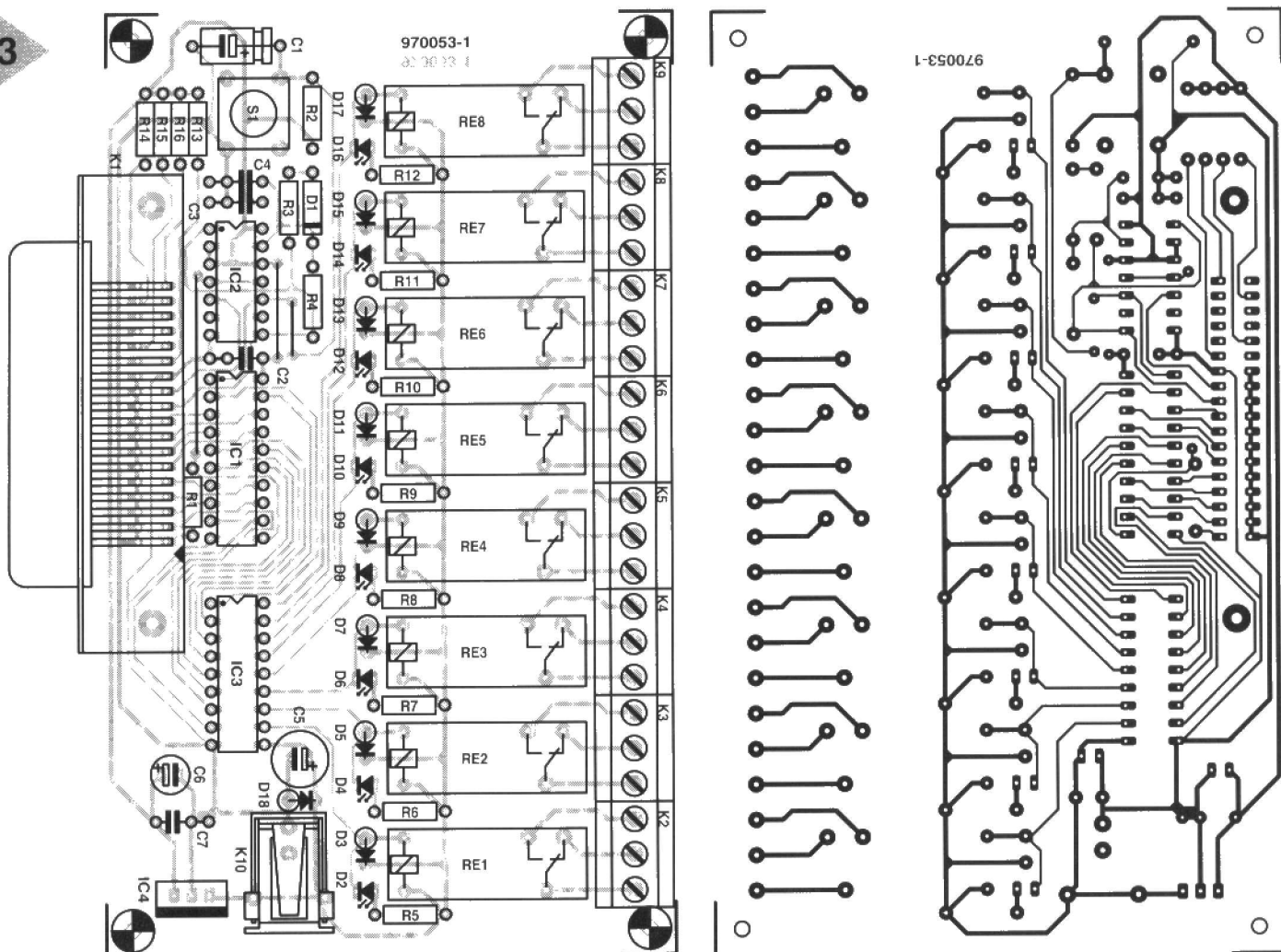


Figure 3. Copper track layout and component mounting plan of the printed circuit board designed for the project (board available ready-made through the Readers Services).

and the \bar{Q} output, low. Because the \bar{Q} output was logic high after the circuit was on, capacitor C4 is rapidly charged via R3 and D1. This keeps the reset input of IC2b logic high, so that the MMV remains inactive. Because the \bar{Q} output drops low after the strobe signal, capacitor C4 will be discharged via R4. This process continues until the level at the reset input represents a logic low, whereupon the bistable is set. The whole process takes about 15 μ s to complete, which is more than sufficient for an acknowledge pulse. The busy signal is generated virtually in parallel with the acknowledge pulse. The process involves the set/reset inputs of bistable IC2a. During the strobe pulse, the set input is logic low and the reset input, high. Consequently the Q output is pulled logic high. The computer then sees a logic high busy signal. At the end of the strobe pulse, the set input of IC2b is returned to high, and the reset input to low via the \bar{Q} output of IC2b. The

bistable is reset, and the busy signal becomes inactive.

Because the digital outputs of IC1 are not capable of controlling a relay coil, a series of current boosters (buffers) is connected behind the IC. These buffers do provide the current necessary to operate a relay reliably.

The buffers are contained in IC3, an ULN2803 integrated circuit (from Sprague). They are actually transistor drivers with an open-collector output. Each of these outputs is capable of energizing the Siemens 'E-card' relays on the board. Each relay coil has a shunt diode which protects the switching transistors against voltage surges. Also in parallel with the relay coils are LEDs which provide a visual indication of the relay contact status. If the relevant driver transistor conducts, the relay is energized and the associated LED comes on.

As already mentioned, the card has an internal reset network, R2-C1. Manual resetting is made possible by the addition of S1. Four pull-up resistors, R13-R16, force a logic high level on a number of printer port inputs (error, select, reset and +5 V).

That only leaves the power supply! Diode D18 acts as a polarity reversal protection, while IC4, an 7805, changes any direct voltage between 8 and 18 V into a stable supply potential of 5 V.

CONSTRUCTION

Building this circuit is unlikely to cause problems if you use the ready-made printed circuit board supplied through our Readers Services. As you can see in Figure 3, the board design is pretty spacious which makes fitting the parts really easy. It is recommended to start the construction by fitting the wire links so that these are not forgotten later. Next, mount the connectors, the passive components and the semiconductors, in that order. Having fitted the reset button, the circuit is ready for use, that is, as far as the hardware is concerned.

ALL LEDs REMAIN OFF

Give the completed printed circuit board a thorough check before you start testing it. Switch off the computer, connect the circuit to the PC's printer port (LPT1:) and make sure the relay card is properly powered by a mains adaptor. Next, switch on the computer and see what happens. If everything is all right, all LEDs will remain off. No light, good light, in this case!

In rare cases the acknowledge pulse may be too long at 14 μ s. Should this problem occur, the value of C4 may be reduced, observing a minimum value 100 pF.

Next, launch GW-BASIC or QBasic and type in one of the example

COMPONENTS LIST

Resistors:

R1 = 150Ω
R2,R13-R16 = 4kΩ
R3,R5-R12 = 1kΩ
R4 = 10kΩ

Capacitors:

C1 = 10μF 63V
C2,C3,C7 = 100nF
C4 = 1nF
C5 = 100μF 25V
C6 = 10μF 63V, radial

Semiconductors:

D1 = 1N4148
D2,D4,D6,D8,D10,D12,D14,
D16 = LED
D3,D5,D7,D9,D11,D13,D15,D17,
D18 = 1N4001
IC1 = 74HCT273
IC2 = 74HCT74
IC3 = ULN2803A
IC4 = 7805

Miscellaneous:

K1 = Centronics socket, PCB
mount, angled pins
K2-K9 = 3-way PCB terminal block,
raster 5mm
K10 = mains adaptor socket, PCB
mount
S1 = push-button, (Multimec CTL3
etc.), 1 make contact
Re1-Re8 = E-Card relay, 12V, 1
changeover contact, eg. V23057
B0002 A201 (Siemens)
PCB 970053-1 (see Readers Ser-
vices page)

necessary, and you can rely on the usual way of printing.

The actual control is very simple indeed using the 'LPRINT CHR\$(x);' instruction offered by QBASIC, where 'x' is a number between 0 and 255. In this syntax, CHR\$ serves to convert a decimal number into a byte. The instruction LPRINT then sends the result to LPT1. Do not forget the semi-colon (;) in the instruction, else another CR-LF (carriage return/line feed) sequence is sent after the hexadecimal character. This sequence overwrites the previously sent data. The hardware in the computer ensures that data is being sent to the printer port, and that the strobe pulse is generated.

Lots of projects may be developed out of the example programs shown here.

THE ADVANCED APPROACH

Although many of you will not fail to see the beauty of simplicity when it comes to controlling the card in software, advanced programmers will want to go further. The use of the OUT instruction provides additional possibilities to the programmer, for example, the use of multiple printer ports. The following sequence is recommended:

Step 1: de-activate the strobe output by writing '0' to address 37AH (if you use LPT1:) or 27AH (if you use LPT2:). Doing so causes the strobe output (pin 1 of the printer port) to change to '1'. Summarizing, use the instruction OUT 37AH,0.

Step 2: write data to address 378H (LPT1:) or 278H (LPT2:). These data will appear (in non-inverted form) at pins 2-9 of the printer port, where pin 2 represents the LSB (least significant bit). Summarizing, use the instruction OUT 378H,x.

Step 3: generate a strobe pulse by writing a '1' to address 37AH (or 27AH). This causes the strobe output (pin 1 of the printer port) to drop low ('0'). Summarizing, use the instructions OUT 37AH,1 followed by OUT 37AH,0.

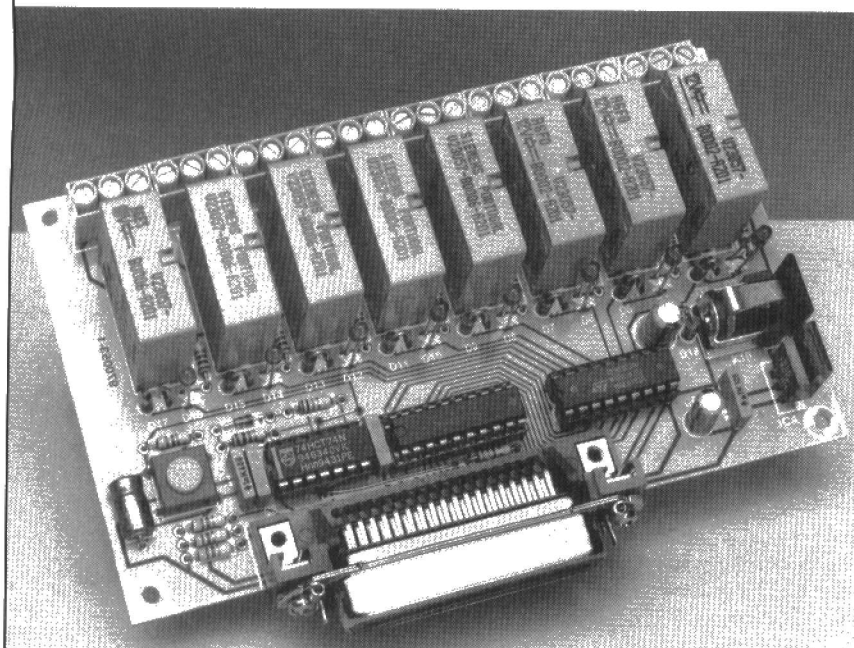
MAINS VOLTAGE SWITCHING

The relay card is not designed to switch the mains voltage (240 V). Although the electrical ratings of the relays do allow the use of the mains voltage, the PCB layout and the isolation distance of the PCB terminal blocks are the restricting factors. Low voltage can be switched without problems, however. When alternating voltages are used, the relays can switch up to about 4 A. In the case of direct voltages, the maximum ratings are about 10 A at 20 V, and 1 A at 45 V.

(970053-1)

programs. After running such a program, it may be halted (after some time) by pressing the Esc(ape) key. Because the relay card mimics an ordinary printer, OUT instructions are not

Figure 4. An early prototype of the relay card.



Simple running lights

REM SIMPLE RUNNING LIGHTS, ALSO FOR TESTING THE CARD

```
DO
  LPRINT CHR$(1);
  LPRINT CHR$(2);
  LPRINT CHR$(4);
  LPRINT CHR$(8);
  LPRINT CHR$(16);
  LPRINT CHR$(32);
  LPRINT CHR$(64);
  LPRINT CHR$(128);
  LOOP UNTIL INKEY$=CHR$(27)
END
```

8-bit counter

REM BINARY COUNTER

```
DO
  FOR X=0 TO 255
    LPRINT CHR$(X);
    FOR Y=0 TO 1000: REM DELAY LOOP
      NEXT Y
    IF INKEY$=CHR$(27) THEN EXIT DO
  NEXT X
  LOOP
END
```

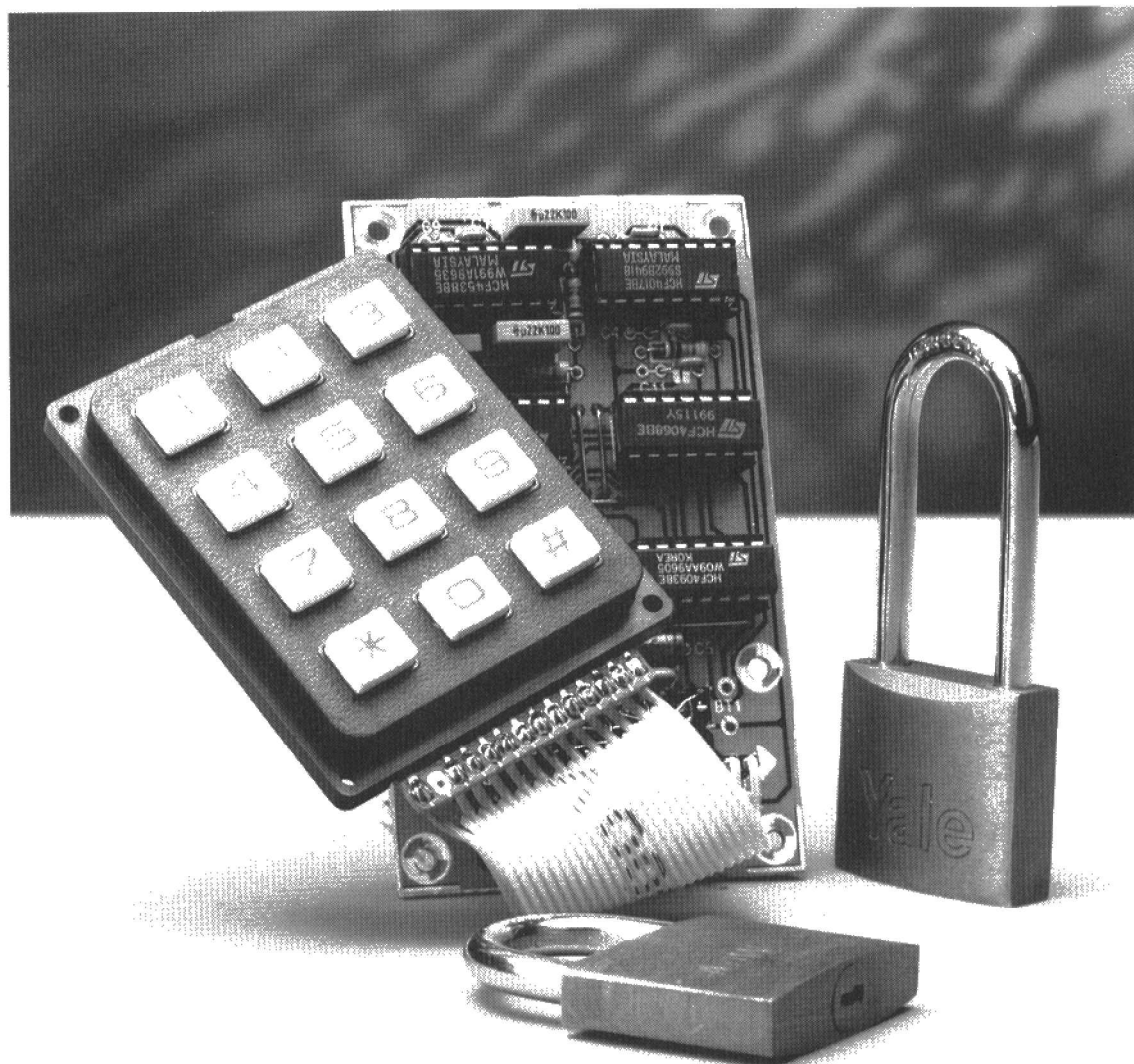
Random contact switcher

REM RANDOM GENERATOR

```
DO
  X=255*RND
  LPRINT CHR$(X);
  FOR Y=0 TO 1000: REM DELAY LOOP
    NEXT Y
  IF INKEY$=CHR$(27) THEN EXIT DO
  LOOP
END
```



electronic code lock



The electronic code lock described is straightforward to build and may be used for a multitude of purposes. All components used are readily available from most electronics retailers. The code consists of six digits which are entered via a small keypad. The output of the lock is enabled only if the keyed-in code is correct.

Design by H. Kutzer

INTRODUCTION

Electronic code locks may be arranged in a number of ways – of late, most of them are based on a microcontroller, but unfortunately not everyone has the means to program these. Others use dedicated ICs that simplify their design, but these devices are invariably difficult to obtain. The lock described in this article uses standard components.

The code is built up from six digits entered via a keypad. These digits may be chosen at random and may occur more than once (which is not possible in all locks). When the code has been entered, the output is enabled when the 'unlock' key is pressed.

by key-switches S_1 – S_{12} , which may be standard push-button types arranged appropriately, or be contained in a suitable keypad. If the latter is used, #-key S_4 functions as the 'unlock' key. For this purpose, the key is linked directly via the keypad connector to the output gate of IC_{2d} . The keys are mutually decoupled by diodes D_1 – D_{12} . The *-key, S_{12} , may be used as a spare entry key or as a reset key by linking it to AR.

The coding module is marked in the diagram with 'socket 1'. Depending on the relevant code, its inputs 0–9 are linked to outputs A_1 – A_6 . Unused keys are linked to AR.

The design is based on monostable

The mono time of IC_{3b} is about 20 milliseconds. The internal output resistance of this MMV (pin 10) and capacitor C_3 form a low-pass filter. This filter delays the clock signal to the counters with respect to the period when the counters are enabled. This means that when the first digit is entered output Q_1 of IC_4 goes high. If the digit is correct, output A_1 of the coding module also becomes high. Consequently, the output of NAND gate IC_{2a} , which is linked to A_1 , briefly goes low and the output of IC_1 momentarily becomes high. This high pulse is 'cleaned' by low-pass filter R_2 – C_4 , which is possible since the clock input of a 4017

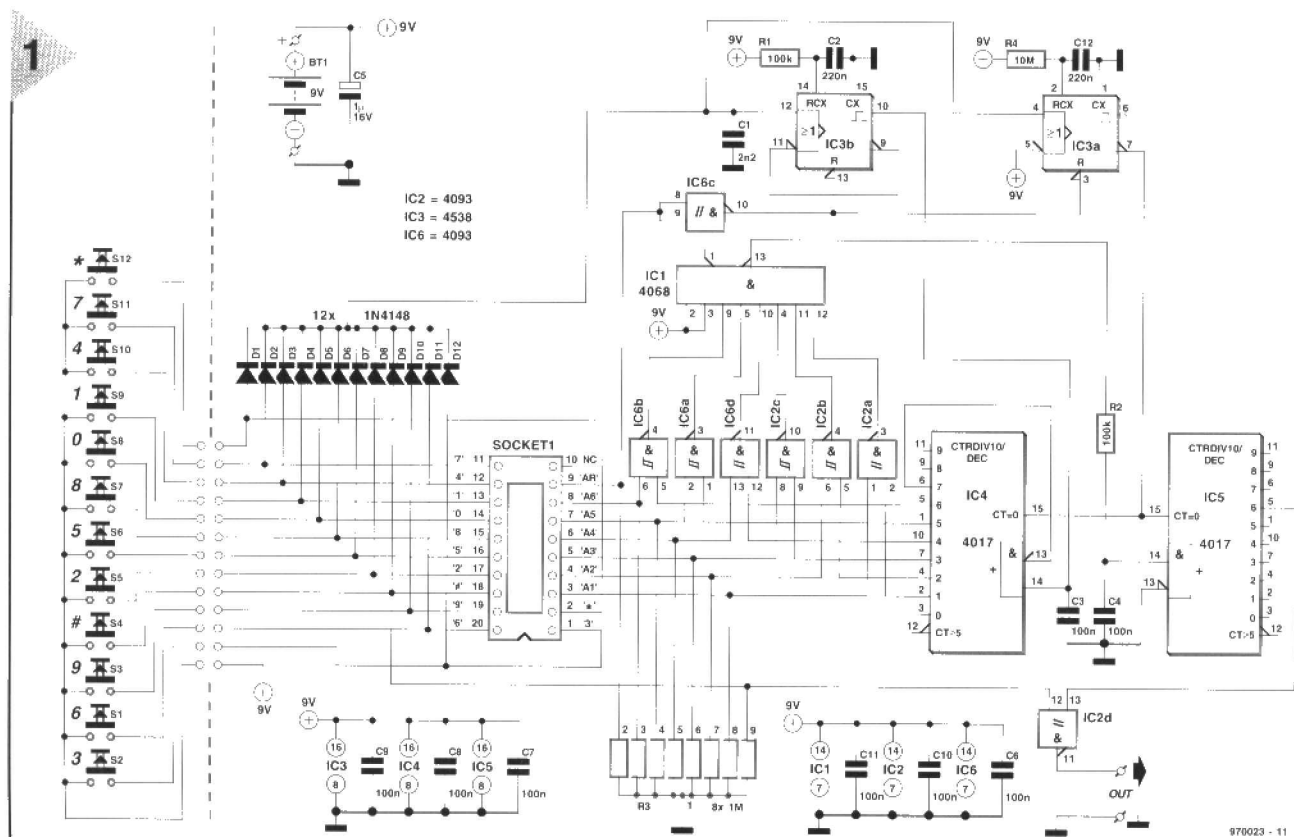


Figure 1. The code lock consists of a keypad, a coding module, and some logic circuits that compare the programmed and entered code numbers.

The code is programmed in with the aid of a coding module that is made simply from an IC socket which has been wired appropriately – see Figure 4.

Owing to the use of CMOS ICs, the lock draws a very small current: the quiescent current is only $0.6 \mu A$, so that battery operation is no problem.

CIRCUIT DESCRIPTION

The circuit diagram of the lock is shown in Figure 1. The code is entered

multivibrators (MMVs) IC_{3a} and IC_{3b} and decimal counters IC_4 and IC_5 . When the circuit is in its quiescent state, the \bar{Q} -output, pin 7, of IC_{3a} is high and both counters are in the reset state. When one of the keys is pressed, both MMVs are triggered, whereupon the counters change state. Capacitor C_1 debounces the keys.

The time constant (mono time) of IC_{3a} is about 2 seconds during which time the counters are enabled. Each subsequent key operation adds a further 2 seconds, so that after 12 seconds the circuit is in the 'accept' state.

behaves as a Schmitt trigger.

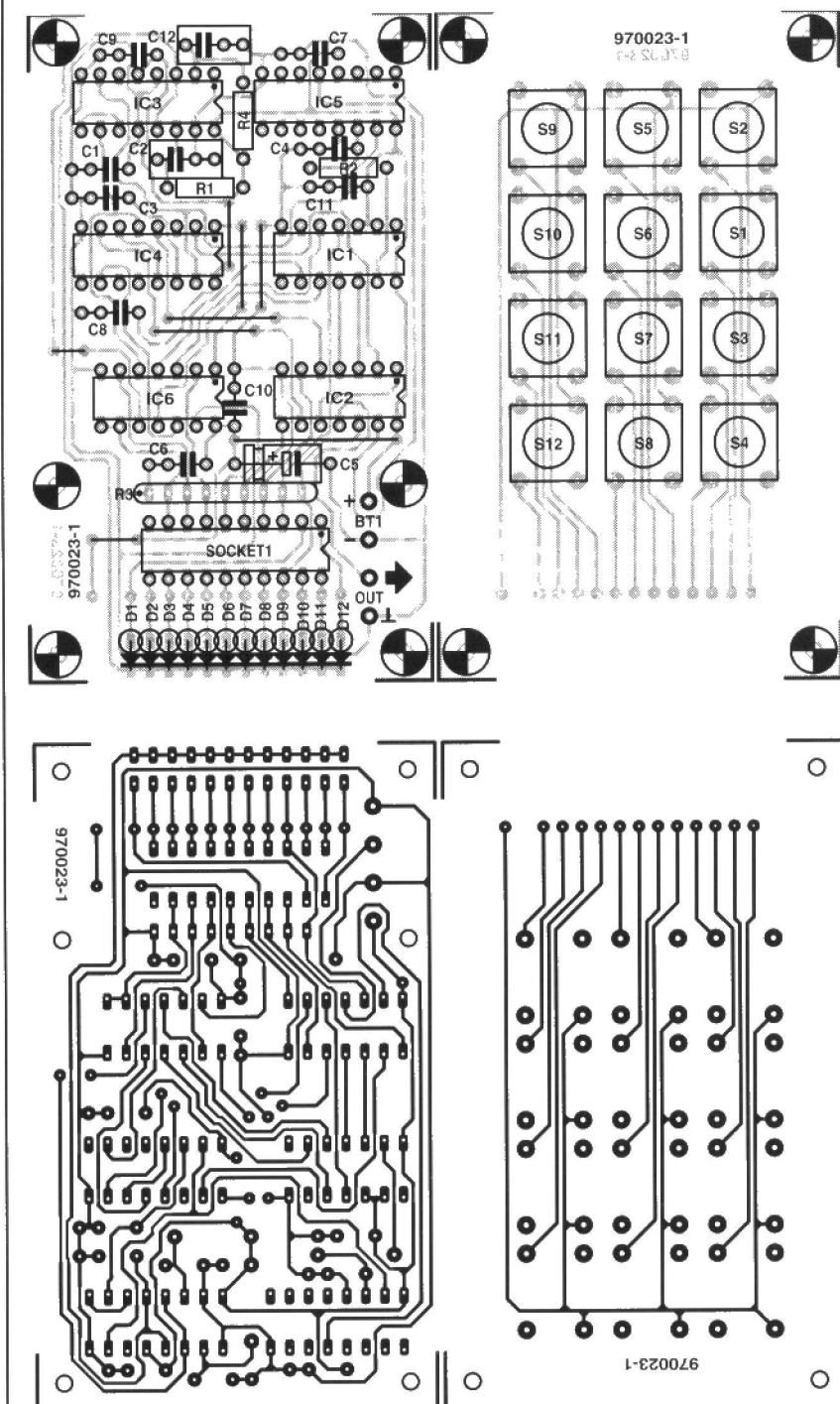
Circuit action for the subsequent digits is the same. If all digits entered are correct, output Q_6 of IC_5 goes high when the sixth digit is keyed in. When 'unlock' key # (S_4) is then operated, the OUT(put) of IC_{2d} changes from high to low. This change of level may be used, for instance, to energize a relay that in turn operates a door opener or similar.

The circuit is reset by IC_{3a} two seconds after the sixth key has been operated.

SAFEGUARDS

To make unauthorized operation of the lock virtually impossible a number

Figure 2. The boards for the keys and the remainder of the circuit are interconnected by 13-way flatcable and appropriate connectors.



CONSTRUCTION

The code lock is intended to be built on the two printed-circuit boards shown in Figure 2. One of these is intended for the 12 push-button keys and may be replaced in its entirety by a ready-made keypad. The second board is intended to contain the remainder of the circuit.

In view of the small number of components, completion of both boards is simplicity itself and should not take more than half an hour alto-

Parts list

Resistors:

$R_1, R_2 = 100 \text{ k}\Omega$
 $R_3 = \text{array, } 8 \times 1 \text{ M}\Omega, \text{ with common terminal}$
 $R_4 = 10 \text{ M}\Omega$

Capacitors:

$C_1 = 2.2 \text{ nF}$
 $C_2, C_{12} = 220 \text{ nF}$
 $C_3, C_4, C_6-C_{11} = 100 \text{ nF}$
 $C_5 = 1 \mu\text{F, } 16 \text{ V}$

Semiconductors:

$D_1-D_{12} = 1\text{N}4148$

Integrated circuits:

$IC_1 = 4068$
 $IC_2, IC_6 = 4093$
 $IC_3 = 4538$
 $IC_4, IC_5 = 4017$

Miscellaneous:

$Bt_1 = 9\text{-V alkaline battery}$
 Socket 1 = DIL20 IC socket
 $S_1-S_{12} = 12 \text{ off push-button switch, e.g., Multimec CTL13, or ready-made keypad, 12+common, e.g. Velleman (from Maplin)}$

of safeguards have been incorporated into the design.

- When a digit not forming part of the code is entered, the level at output AR of the coding module changes from low to high, which causes the two MMVs to be reset instantly.
- To ensure that counter IC_4 cannot run on at undesired instances, for instance, when a digit forming part of the code is entered repeatedly,

pin 6 of IC_4 (Q_7) is interlinked with ENA(able) input pin 3.

- The interlinking of pins 9 and 11 of IC_{3b} makes retriggering of the MMV, for instance, by rapid pressing a key a number of times, impossible.
- The resistors in array R_3 ensure that the levels at the inputs of the NAND gates in IC_2 and IC_6 are defined at all times.

gether. Do not forget the wire bridges and make sure that the ICs and electrolytic capacitor C_5 are fitted correctly. Also, note that the mark on array R_3 indicates the common link of the resistors and that this should be facing C_6 . The completed prototype boards are shown in Figure 3.

The boards are best interlinked with the aid of 13-pin SIL connectors, one (male) fitted on the mother board and the other (female) terminating a length of 13-way flatcable soldered to the relevant terminals on the keypad (or board). Both boards have provision for a number of through-spacers (not shorter than 10 mm) by which they can be assembled as a sandwich.

The final assembly and housing of the lock depend, of course, on the

3

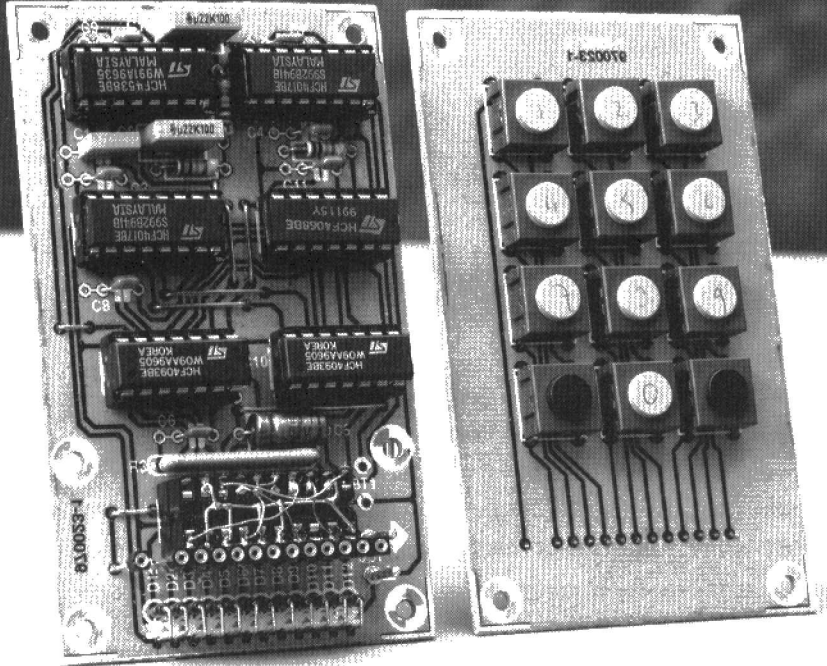


Figure 3. Completed prototype boards. The title photograph shows the lock with a ready-made keypad.

application.

Power may be derived from a 9-V alkaline battery. The quiescent current is about $0.6 \mu\text{A}$ and the operating current during the short periods when a key is operated is 1.6 mA.

CODING MODULE

If it is expected that the code will be altered regularly, it is advisable to use a heavy-duty 20-pin IC socket. The code number is set at the upper side of the socket with wire links. It is advisable to start the links by connecting the unused pins to pin 9. These connections may be made in thin standard circuit wire. The coding links should be made with 0.1–0.2 mm dia. enamelled copper wire.

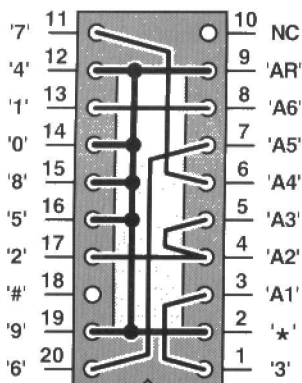
Figure 4 shows an example of a coding module arranged for code number 322761. Digit 3 is obtained by

interlinking pins 1 and 3, digit 2 by interlinking pins 17 and 4, 5, and so on. Note that since digits 0, 4, 5, 8, 9 and * are not used in the code, the relevant pins are connected to pin 9 (output AR). Any other 6-digit code can be programmed by appropriate links between the various pins.

[970023]

4

Code = 322761



970023 - 12

Figure 4. The code number is programmed by linking the digit-inputs in correct sequence with outputs A₁–A₆. Unused digit-inputs must be linked to AR.

A few days ago my wife phoned me at work. She wanted to play one of her favourite CDs, but could not get the CD player to work. "Which knob do I have to press", she asked. Of course, the problem was solved quickly enough, but it made me reflect, rather disconcertedly, on what I read some time ago in a magazine. In a short article, the author (a man) maintained that electronic equipment, cars, cameras, and others, are designed by men for men.

I wondered then, and some days ago again, if that was really true. Do men in the design of equipment make the operating controls needlessly intricate, and could this be prevented with some feminine insight? Earlier, I had dismissed the thought as being very unlikely. But the telephone call from my wife threw up fresh doubts in my mind. Were those symbols on the operating controls of our CD player really clear to everyone? Should a designer expect that every user clearly remembers at all times what the function of a tape monitor or mute control is?

That evening I went home with mixed feelings on the subject. Had all the equipment at home really been designed with only 'superior males' in mind? When I got home, I immediately confronted my wife with these doubts. Why did she think she was not able to get the CD player to work? Were there any typical male-inspired flaws in the design or layout of the operating controls?

She looked at me in surprise. "I don't think there is anything wrong with the equipment", she said, "it's just that I don't use it all that often and, to tell you the truth, it doesn't interest me much".

"But what would you have done if I had not been there to help you", I asked, since I wanted to get at the bottom of it.

"Well, I would probably have put the radio on", she said laconically.

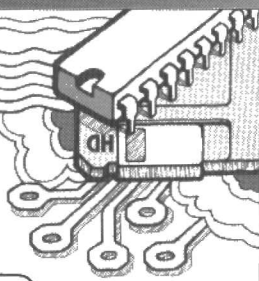
"And would you have been happy with that?", I asked.

"Oh, yes, of course, don't worry about it", she said.

I left it at that, but I must confess that I still don't know whether the writer of the magazine article had a point. I keep wondering about it.

[SvR - 975060]

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SEPTEMBER 1997

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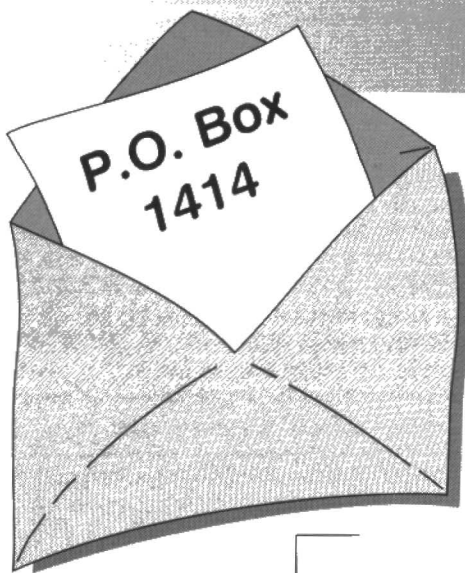
- extension PCBs (3-in-1) 960033-2 17.00 34.00

- IC20/30/40 ispl.S1016 966506-2 27.50 55.00

APRIL 1996

U2402B Battery Charger 950120-1 12.00 24.00

Certronics Interface 960052-C 16



design offering an EPP/SPP selection in the BIOS, it is recommended to use the design as published in the March 1997 issue.

The PCB whose artwork is printed here is not available ready-made through our Readers Services.

Unidirectional version of EPROM Programmer

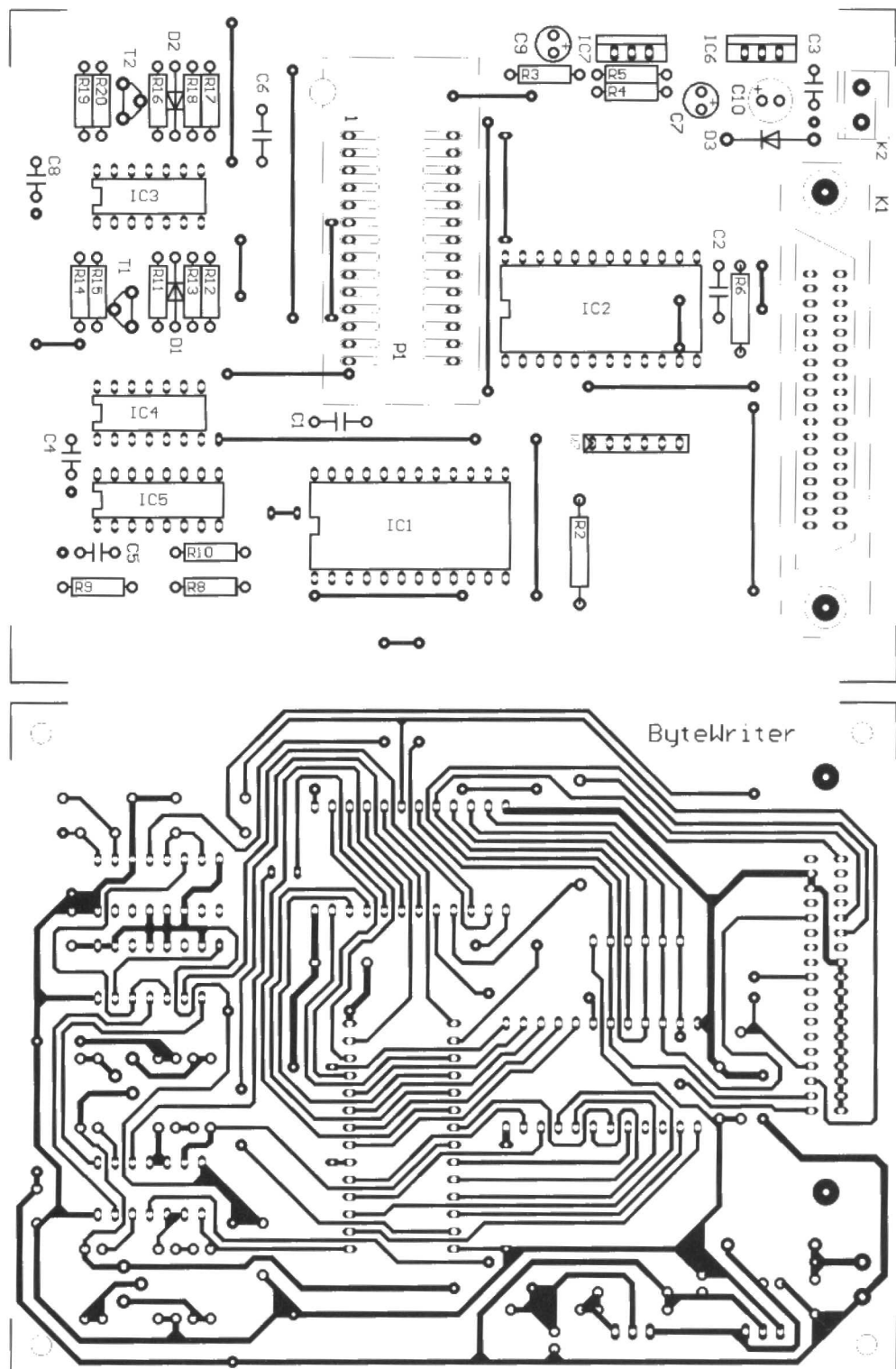
The EPROM programmer published in your March 1997 magazine can only be used with PCs whose printer port can be set to **EPP mode**. My PC is a rather old type with just an SPP port. Reluctant to invest in an extra insertion card, I designed a printed circuit board for the unidirectional version of the programmer, as described by the author, Mr. Rijkogel, on the 'Software for Electronics 96-97' CD-ROM which I obtained from Elektor Electronics.

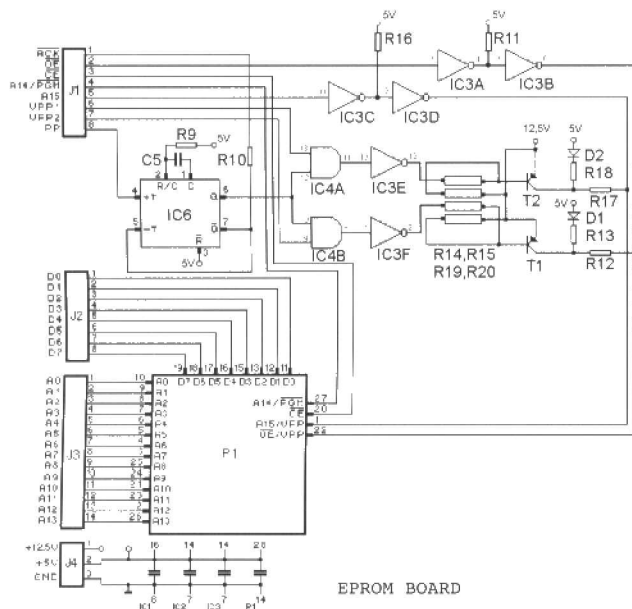
Since this PCB design may be of interest to other readers of your magazine, I am pleased to offer it for publication at your earliest convenience.

P. Heck

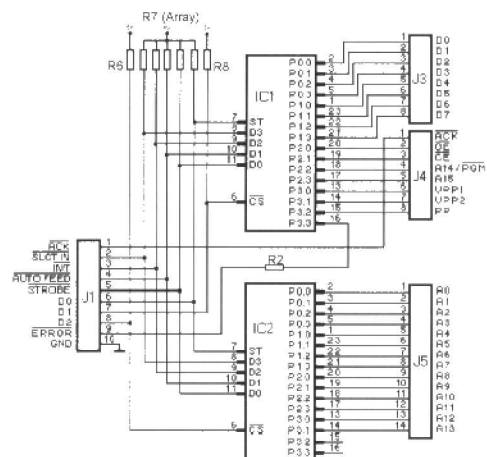
We are very grateful for your PCB design as we believe this may help several readers wishing to build the unidirectional version of the programmer. There is also a small modification in the circuit diagram (with respect to the one found on the CD-ROM), so we'd better print that as well.

A built up circuit board sent to us by Mr. Heck was tested in our design laboratory and worked perfectly on several computers (including desktop machines and one laptop), using SPP mode printer ports and, of course, the software that may be found on the CD-ROM (PROMMER.EXE). So, if you have an older PC, this may be a good work around. If your PC is of a more recent





EPROM BOARD



UNIDIRECTIONAL INTERFACE

COMPONENTS LIST

Resistors:

R1 = not fitted
R2, R10 = 100Ω
R3 = 220Ω
R4 = 3kΩ
R5 = 4kΩ
R6, R8 = 4kΩ

R7 = 4kΩ 7 SIL array
R9 = 12kΩ
R11, R16 = 2kΩ
R12, R17 = 68Ω
R13, R18 = 1kΩ
R14, R15, R19, R20 = 10kΩ

Capacitors:

D1, D2 = 1N4148

D3 = 1N4001
T1, T2 = BC327-40
IC1, IC2 = 82(C)43
IC3 = 74(LS)06
IC4 = 74HCT08
IC5 = 74HC(T)4538
IC6 = 7805
IC7 = LM317T

Miscellaneous:

K1 = 25-pin sub-D plug, PCB mount, angled pins
K2 = 2-way PCB terminal block, raster 5mm
P1 = 28-way ZIF socket
PCB not available ready-made

CORRECTIONS & UPDATES

68HC11 Emulator February 1997 - 970008

If the reset does not work properly it is recommended to fit a 100-nF capacitor near C5, between pins 1 (REF) and 4 (ground). In case there is insufficient room for C10 (located inside the socket), then this part (preferably SMA) may be fitted at the under-

side of the board.

Earth Leakage Meter June 1997 - 970046

The article states incorrect type numbers for the inductor cores. Although this does not affect the operation of the circuit, problems may arise when the circuit is built into the specified case. The correct core type is:

NOTE ADDED TO ELETRO JUNE 1997 P.39

TN26/15/10-3C11, $A_1 = 5\mu\text{H}$
(Philips Components)

Advanced LCR Meter April, May, June 1997 - 970028

Crystal X1 has to be suitable for oscillation at its fundamental frequency (24.576 MHz). A number of kit and parts dealers apparently supply third-overtone crystals,

which produce oscillation at 8.192 MHz in this circuit. The frequency measured at the adjustment point on the PCB is then 4.096 MHz. The problem may be solved by changing C1 to 68 pF, and shunting it with an L-C series network consisting of a 1-nF capacitor and a 4.7-μH inductor. These parts are fitted at the underside of the board.

REMINDER

MICROPROCESSOR CONTEST 1997

If you haven't sent us your microprocessor project yet, remember that the closing date for contest entries is 15 September 1997.

The Contest rules and an overview of the available prizes (with a total value of more than £10,000) may be found on pages 6-10 in the July/August 1997 issue.

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